Building Balls

Final Design Report

JumpSport Inc.

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Executive Summary

JumpSport, a major trampoline company, has requested Cal Poly to design a custom play-structure consisting of large diameter balls with two types of connectors-long rod connections and very close connectors (for a ball-to-ball type connection). By the end of the project, appropriate testing will be carried out on the connections and a full-scale model will be constructed.

After an extensive design process, our team of three decided on a rod connection style for both the long and short connectors. These consist of a hook that latches into a loop protruding from the ball where the hook is attached by a power screw. The hook/power screw assembly is covered by a sleeve and plunger style cover assembly. The sleeve rides the threads of the power screw to tighten or loosen the fit of the plunger surface to the ball. Thus, the plunger acts to cover the hook while creating a suction to the ball so that the connection stays tight. For the short connector length is equal to approximately four inches so that adequate space is provided for a hand or foot to fit between the balls. The long connector is approximately four feet in length. This length is equal to the sum of one ball diameter and two short connectors so that at any time the created play-structure can be easily altered.

The prototypes will be produced by the team-Gary Johnson, Rosalie Mangione, and Steve Rose. The initial parts will be machined and an at home molding process will be used to replicate parts. Purchased parts in conjunction with these self-made parts will be assembled by the team.

Structural testing was conducted on both styles of connectors. The ball used to adequately measure the desired features are produced by Mondo. This Mondo product uses a plastic we intend to use except for a larger diameter. Testing on the Mondo products allows us to obtain the necessary test results without the need to produce a ball with the correct diameter. These tests include but are not limited to maximum weight capacity, tensile and shear tests on the loop alone, etc. This data was used to determine Young's Modulus for the Mondo ball's plastic. This information was useful in relating our calculated data to our tested data.

In the end, a full scale prototype was made and assembled using an alternative to the Mondo ball so as to meet the diameter requirements. The reason for a full scale prototype is to model the connection points also designed by the team. From this full scale prototype we learned that simply adhering loops to the balls is not an appropriate substitution because it cannot even handle the static loads of the structure simply supporting itself. However, this prototype did yield useful information about the ergonomic qualities of the structure. Connecting a ball that will be suspended in the air proved difficult for two adults and would be impossible for young children alone. Due to these problems, a decision cannot yet be made without further testing using more appropriate materials. However, as the project stands currently, it is not a viable product.

Introduction

Building Balls is a Cal Poly senior project created to design an inflatable, customizable play structure for private use. The goal for this project is to hit the home-playground equipment market with a new, innovative product that can sell to families around the United States. This project is sponsored by

JumpSport, an established trampoline company. JumpSport already has many products on the market targeting all ages and for multiple uses. Exercise is made fun with trampolines and is appropriate for children and adults alike. This new product described in this paper is designed to do the same thing—make exercise fun, safe, and for the whole family. Since Building Balls is designed for families, children of 7 years and older will be able to assemble, disassemble, and, of course, enjoy the structures they create. The premise of the design of Building Balls is a collection of large-diameter, inflatable balls that can be connected together in multiple ways. This leaves the user the ability to create multiple structures and explore one's creativity. The primary focus of the project described below is the design of the mechanisms to connect these balls together either adjacent to another ball or to an intermediate rod.

Management Plan

Each member will be assigned tasks as necessary. As of now, the roles are as follows: Gary Johnson keeps track of the timeline and deadlines, Steve Rose records the minutes from all conference meetings, and Rosalie Mangione is in direct correspondence with the sponsor (i.e. emails, etc.). Currently, Steve and Gary have been in charge of the solid modeling of the design while Rosalie has focused on the documentation of the process. Calculations were conducted by Rosalie and Steve and Gary decided the loop locations on the balls. Regarding the first series of tests, all three of us will need to be in attendance as the appropriate faculty member on campus assists us in running the equipment. If manufacturing of the molds can be conducted on campus, Rosalie will prepare the molds for machining as Gary and Steve take the opportunity to improve their machining skills with her guidance. If the plastic processes can be executed on campus, all three of us will assist as necessary and be directed by the appropriate faculty member. After the second series tests, any redesigning will be a group effort in order to complete it as soon as possible.

Regarding the timeline, the first test series will begin in mid-February and initial prototyping will begin soon after. A memo of our progress will be completed by March 8th. Our final prototype should completed by May 8th at which point the second series of testing will begin. Our final report will be finished on Friday, June 3rd, and the design expo will be the day before on June 2nd. The design expo will be a time for JumpSport to come down to Cal Poly and view the finished prototype and hear our presentation on the project. The full list of deadlines and a detailed timeline is available in the Gantt chart in Appendix E. We are currently on schedule; we will begin buying materials for our prototypes this coming week. We will then begin machining and assembling our prototypes as soon as we can. We are currently working on a method for testing the yield strength of the Mondo ball's loops. We are also working on tracking down a Shore A durometer to test the material properties of the Mondo ball. In the meantime, we will maintain regular contact with JumpSport to show our progress, approximately once a week or more as necessary.

Background

JumpSport is a small company started in 1997 introducing their "Trampoline Court" safety enclosure. The founder, Mark Publicover was inspired to create this product when family members and friends were injured while harmlessly playing on a trampoline.

Figure 1 JumpSport Power Source Trampoline. Reference: www.jumpsport.com

Since then, JumpSport has created multiple products always improving the safety of trampolines and has opened a concurrent company named AlleyOop. Figure 1 is an example of JumpSport product. AlleyOop is a company that markets full size trampolines similar to JumpSport but the jump bed of the trampoline has two layers as shown in Figure 2. This double bed design increases the amount of energy the bed absorbs from the bouncer thus further emphasizing safety while still having fun.

Figure 2 AlleyOop DoubleBounce PowerBounce. Reference: www.jumpsport.com

In addition, the Publicovers have also developed a line of trampolines for individual use that can be used in gym environments, indoor home environments, and any other place that would not be conducive to a full size trampoline. JumpSport has been awarded multiple awards, including being named the safest trampolines on the market. Now, JumpSport is looking to expand from trampolines to new types of home outdoor play equipment. Therefore, Building Balls was created, with Gary Johnson, Rosalie Mangione, and Steve Rose assigned to create this new design. The team is pictured in Figure 3.

Figure 3 Building Balls Team. Listed from left to right: Gary Johnson, Steve Rose, Rosalie Mangione.

Research and Overview

To begin our endeavor on this innovative product, we researched what currently produced items seemed to match aspects which met the design criteria already specified for Building Balls; inflatable, large diameter balls which can be connected together through some sort of mechanism. Our search led us to exercise balls and hippity-hop balls as shown in Figure 4 below. These balls vary in diameter from 12 inches to 36 inches. They are inflatable, made from a strong but flexible PVC, and hold relatively high pressures, resulting in a rigid, over-sized bouncy play/exercise ball. We envision the balls for Building Balls to have similar characteristics.

Figure 4 Hippity Hop Ball. Courtesy of: http://www.athleticstuff.com/astuff/product.asp?dept_id=3630&pf_id=8045.af

Our design task focuses on researching plastics appropriate for these balls, specifying a thickness for the balls, and designing a mechanism to connect a single ball to another ball and a mechanism to connect a single ball to a rod. American Society for Testing and Material and Consumer Product Safety Commission has specific material and playground codes that dictate the design restraints. A patent search proves this product to be new and innovative.

In addition to our current product research, we researched playground equipment that children enjoy. The goal of reflecting on these playground pieces, though they are not similar to the goal of Building Balls, is to study the competitors in the market we are aiming to target. Children enjoy swings, climbing on things, things that bounce or slide, etc. We intend to keep these additional play items in mind as accessories which would be possible for additions to our base design for future projects.

A large design consideration that must not be overlooked is manufacturability. Since this product is intended to be produced in large quantities, it is important to design parts that can be as easily manufactured as possible. For example, the balls will more than likely be rotationally molded. This process, albeit slow, is very conducive for hollow objects. The components include a two piece mold, an oven, and a rotating mechanism that holds the mold. After filling the mold with the appropriate amount of the specified plastic and dye, the mold is closed, placed in the oven, and allowed to rotate an extended amount of time until the plastic is fully mixed with the dye. After being removed from the oven, the mold is immediately quenched resulting in a consistent thickness and evenly colored product. Figure 5 pictures a very large rotary mold where the mold is within the silver barrels which are actually heating chambers.

Figure 5 Very Large Rotary Mold. Reference: http://www.ask4plastic.com/mimages/Bi%20Axial%20Rotational%20Molding%20Machinery_03546.jpg

In the mold, additional points of interest can be added. For our purposes, we will be adding portions which will result in solid rings around the seam of the mold. As featured on the ball being released from a rotary mold in Figure 6, we envision our balls to have a similar solid, protruding ring except smaller and more than one ring per ball. In considering the design of the connectors, manufacturing processes will also be considered.

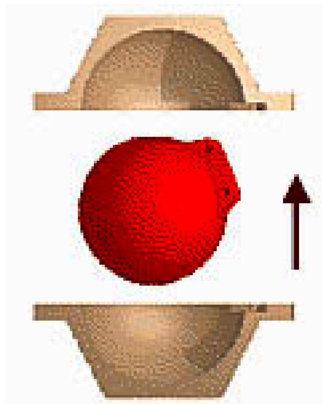


Figure 6 Ball being removed from rotary mold.
Note the additional piece on the ball, we intend to make something similar with rings rather than a band.
Reference: http://plastics.turkavkaz.ru/processes/molding/rotational-molding/

Regarding the materials for each piece, there are multiple plastics which we must consider. For the rod, metals will be considered in addition to hard plastics to provide rigidity and strength. We will decide upon the materials by comparing the strength required and the strength of each material in addition to ease of manufacturing.

Design Development

Objectives and Requirements

Our goal for Building Balls is to create a functioning prototype that contains ball-to-ball and ball-to-rod type connections. We have designed ball-to-ball connectors and decided where the rings on the ball will be molded to create the maximum amount of configurations using 10 balls. In order to quantify the customer's desires and requirements for Building Balls, we created a House of Quality. In a House of Quality, customer requirements are listed and compared to engineering specifications so as to put all requirements into measurable units. The House of Quality for Building Balls consists of 23 requirements converted to 24 measurable specifications. We created the list of customer requirements for this House based from a personal meeting we had with the JumpSport team. In this meeting, we discussed design parameters as well as the goals for Building Balls. In addition to this personal meeting, we have had several conference calls to confirm our progress on the project and ensure that our interpretation of the customer requirements is what JumpSport had described. Customer requirements include the need that Building Balls be fun, safe, easy to assemble and disassemble, weathering consideration from the sun and rain should be minizimed, etc. Additionally, Table 1 lists the requirements that JumpSport specified as "must-haves" for the design. The House of Quality is located in Appendix A. After establishing an extensive list of customer requirements, we translated these requirements into measurable and quantifiable items. For instance, fun was translated to the number of configurations possible, assembly time necessary, number of colors and parts in a set, total weight capacity, buoyancy factor, and space required. It is clear, a single customer requirement may require multiple engineering specifications to fully define the requirement but it is that fact that makes this House analysis useful. From this House, we can clearly read what is necessary to measure and in turn, what must be conducted to meet each requirement. Table 2 is a table of the engineering specifications used in the House. The Risk column describes the priority of each description, L refers to low, M to medium, and H to high priority. The Compliance column refers to how the specifications will be assessed as met, I refers to inspection, T to test, S to similarity in other existing designs (current products), and A to analysis.

Table 1 Design parameters specified by JumpSport as essential

	Design Parameters
1	Inflatable
2	Causes full seal with ball
3	No pinching areas
4	Double lock mechanism
5	Minimal number of parts
6	Ease of construction while standing on ground
7	Ease of construction while suspended in the air on product
8	Connections can be interchanged while ball is inflated or deflated

Table 2 Engineering Specifications.

Spec #	Parameter Description	Requirement Or Target (units)	Tolerance	Risk	Compliance
1	Size	30" diameter	± 0.5 in	L	I
2	Time for Assembly	15 Minutes	Max	M	T
3	Space Required	200 sq. ft.	Max	L	I, T
4	Age	7+ years	Min	H	S
5	Lifespan	5 years	Min	H	A
6	# of configurations	5	Min	H	A
7	Operating Weight	5 lbs/ball	Max	L	A, T
8	Weight Capacity	2000 total, 250 per ball-center load	Min	H	A, T
9	# of Colors	1 per type of connector/ball	Min	L	I
10	Rod Deflection	0.00 in	+.02 in	M	A
11	Hardness	35-50 Shore A	±10	H	T
12	Number of Parts	10 per fixture	Max	L	I
13	Number of Methods of connectivity	2	Min	L	I
14	Buoyancy	2000 lbs	Min	M	A
15	Packaging Size	3 ft x 1 ft x 1 ft	±1 ft^3	L	I, T
16	Percentage of Requirements met	100%	Min	H	I, T, A
17	Water Absorption Factor	0	Max	L	I
18	Temperature of Surface	<10°F + T_{amb}	Max	H	T, A
19	UV protection	Reflectivity > .9	Min	H	T, A
20	Air Pressure	15 psi	Min	L	A
21	Time for Disassembly	15 min	Max	M	T
22	Number of Parts in Mold	30	Max	M	I
23	Material Cost	$1 per ball	±$1	M	I
24	Manufacturing Cost	$1 per ball	±$1	M	I

In addition to listing the customer requirements and engineering specifications, the House of Quality also includes an assessment of how competitors meet the customer requirements we propose. Competitors we assessed include bounce houses and the standard home playground structure consisting of a simple monkey bar set, swing, and slide. Though these competitors do not match the vision of Building Balls, they may enlighten us on a requirement that needs more attention than we initially presumed. Although we found that the bounce house meets more requirements than we expected, both seem to miss the requirement of being lightweight, floatable, and quick to assemble.

The House also specifies the priority of each engineering specification and which specifications we believe will be the most difficult to achieve. We determined the total weight capacity and the weight capacity of each individual component is to be of utmost priority. This result came about because multiple top priority requirements (fun factor, safety factor, and sturdiness factor) are defined by the two weight capacities. Despite its priority, weight capacity is not what we believe will prove to be the most difficult factor to achieve. Rather, we believe protection from UV and keeping the maximum temperature of the surface of each part low to be most challenging. The full House, again, is available in the Appendix. On the right is the competitor assessment and at the bottom are the other components of the House discussed above.

To continue defining the customer requirements and begin generating ideas, we had a preliminary idea generation session. In this session, we went through each customer requirement individually and drew ideas that came to mind for each, some directly related to the project, others not. This procedure was useful because it forced us to consider the options of each of the customer's requirements. Rather than limit ourselves to the confines of the project, we took a day to broaden our scope in which we thought of the extremes of each requirement. Now that we have the extremes, we are able to mix and match ideas for each requirement to see what is feasible, what is not feasible, what is missing, and what needs to be fixed. We believe with this process, in combination with the House of Quality analysis, we have correctly defined Building Balls and its requirements.

Method of Approach

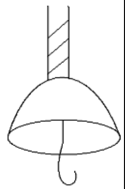
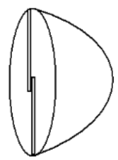
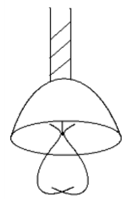
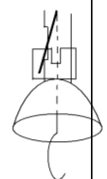
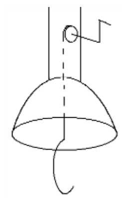
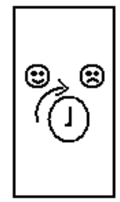
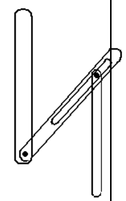
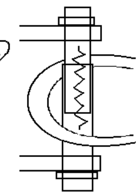
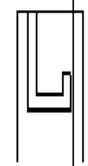
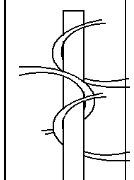
Our design process consists of a research period followed by a brainstorming period. Next, preliminary calculations are made and prototypes are constructed in order to choose the best solution. The table below explains the milestones of our project and the date at which the milestones are to be met. We have also constructed a Gantt Chart to further organize our progression, which can be found in Appendix E. The Gantt Chart specifies the dates of the large milestones and also illustrates the time allotted for each process necessary to carry out the milestone.

Table 3 List of milestones for entire project

Date	Item
12/7/2010	Conceptual Design Review
1/20/2011	Decision on Production Processes
2/1/2011	Design Report
3/8/2011	Project Update Memo
5/9/2011	Hardward Demo
6/2/2011	Senior Project Expo
6/6/2011	Final Presentation

After a second idea generation period, we constructed a Pugh Matrix. This matrix organizes the ideas we generate by column and compares them to a list of requirements the design is expected to meet. For Building Balls, we designated the Mondo Hippity Hop Ball to be the datum; all design ideas were compared to the already manufactured Mondo datum. Below is the Pugh Matrix which highlights the requirements included and the assessment of the ideas.

Table 4 **Pugh Matrix. On the left are requirements that the design is expected to meet, on the right is the design and how successfully it achieves the requirements compared to a datum, the Mondo Ball.**

Concept / **Criteria**	Bike Lock	Hook with Power Screw	Dual Pin Plunger Connection	Cross Tweezer Clamps with Power Screw	Hook with Lever	Hook with Rotation and worm gear	Key Mechanism	3 Pin w/ Slot	Tension Spring Pin	Lock Slot	Toggle Clamp	Mondo Ball
												
Dual Safety	+	+	S	+	+	+	+	S	+	+	+	
Easily Attached	+	S	S	S	S	+	+	+	-	+	S	
Easily Detached	+	S	S	S	S	+	+	+	-	+	S	
Attachable while Inflated	S	+	S	+	+	+	S	S	S	S	+	
Made for Children	+	+	S	+	+	+	+	+	S	+	-	D
Flush along rod	+	+	+	+	+	+	+	+	+	+	+	A
Intuitive	+	+	S	+	+	+	+	S	S	+	+	
Operable in air	+	+	S	+	-	+	+	+	S	+	-	T
Removable Parts	-	+	+	+	+	-	-	+	-	+	+	U
Σ+	7	7	2	7	6	8	7	6	2	8	5	
Σ-	1	0	0	0	1	1	1	0	3	0	2	M
ΣS	1	2	7	2	2	0	1	3	4	1	2	

Bike Lock
A locking technique that would move an internal key sideways in a slot so no movement could dislodge the key. The switch used to move this key would show it is fully rotated by showing a green sleeve and a red sleeve when it is open. Though this is easy to assemble, we fear it may be too easy to disassemble. For example, if someone were to step on the connection, the mechanism could easily unlock and pose as a danger.

Hook with Power Screw
A hook rigidly attached to a power screw that would attach to a protruding ring on the ball. A plunger like cover would cover the hook and ring to ensure no injury occurs due to the hook's exposure. Lastly, a threaded sleeve moves down toward the plunger to lock the hook on the ring. It is possible to design the sleeve twists so that two connections are tightened, one on either end of the bar. This was the design chosen with an additional safety point added to the design in the form of a button. This design is discussed in further detail later.

Duel Pin Plunger
This connection consists of a plunger like cover but instead of hooking to the ring, two pins would go through the hole of the ring and lock in place. The appealing point of this design is that very few parts comprise this design. The prototype proved that this assembly is not easy to construct and the pins are difficult to locate within the hole.

Cross Tweezer Clamps with Power Screw
Similar to the "hook with power screw" idea except instead of a hook, cross tweezers attach to the ring from both sides restricting the motion between the fixture and the ring. As this design is very similar to the chosen "hook with power screw" design, the final diameter of the loop and hook will decide with cross tweezer clamps are necessary.

Hook with Lever
A hook with a plunger like covering but rather than having to thread a sleeve in place, a lever must be pushed down to lock the hook. The second safety or dual safety feature of this design includes a sleeve to cover the lever, leaving the rod smooth without any protrusions. This design was also very appealing but after discussing with JumpSport, the "hook with power screw" design was chosen. The driving reasons the power screw was chosen rather than this lever design were the fewer number of parts with the power screw and less steps to fully assemble the design.

Hook with Rotation and Worm Gear
In this connection, an external key acts as a crank which locks the hook. In order to lessen the torque required to tighten the hook, a worm gear would be put in between the hook and crank location. This not only simplifies cranking but also acts as a dual safety as the worm gear would be designed as irreversible. JumpSport preferred an idea that did not require an external key as it could be easy to lose or neglected in final assembly by the consumer.

Key Mechanism
An external key, such as the crank mentioned in the "hook with rotation and worm gear," would turn, and once it is turned completely, a happy face or other positive signal will show. Otherwise, when it is not fully locked, a frowning face or other negative signal will show. This makes it easy for children to recognize if the rod is properly connected. Again, since this design requires an external key, we chose not to proceed with this design.

Three Pin with Slot
A mechanism that has two buttons exposed to the user and when compressed, loosens the mechanism, and when not depressed, the mechanism locks. This makes for ease of assembly and disassembly. Unfortunately, our prototype showed this idea as very difficult to construct and had many small parts.

Tension Spring Pin
This has the main component as a tension spring internal to a casing that loops through the ring on the ball. The prongs of a rod would then be inserted around the main casing of the spring and pins would be placed on the outer side of the rod through the main casing to lock the ball to the rod. This prototype proved to be difficult to construct like the "three pin with slot" idea with many small parts.

Lock Slot
The lock slot is an idea to be used in conjunction with another idea. This simply shows how a lock can be made for a circular rod when a peg is on the female component.

Toggle Clamp
A four bar mechanism that is self locking once a lever is pushed over the center of member 2. This could be designed in such a way as to close at the exact locking position of the mechanism which is determined by the length and connection points of the four members. Though toggle clamps are used often in similar applications, we decided against this design because toggle clamps tend to require a large amount of force to lock or unhinge. The amount of force necessary is not convenient for a 7 year old whom our designed is geared toward.

Mondo Ball Datum
The Mondo ball consists of a pin which connects a handle through the protruding ring on the ball. This is a nice, simple idea with few parts but requires that the ball be deflated when the pin is inserted. JumpSport made it clear that the connections should be removable or added at all times whether the ball is inflated or deflated.

Final Design

Design Selection
We built models of all of our designs. This proved to be extremely useful in showing us the positives and negatives of a given idea and the ease of assembling each idea. Though the prototypes were made from simple materials, the construction factor and feasibility factors were evident from the prototypes. We

learned that the bike lock would have a protruding piece from the rod if it were implemented. The "hook with power screw" seemed promising as it is easy to assemble and manufacture. The "dual pin plunger connection" did not seem very rigid from our prototype. It could also pose a problem trying to manipulate it while being significantly raised off the ground. The "cross tweezer clamps with power screw" also seemed promising in conjunction with the power screw idea. The "hook with lever" prototype also looked promising as it is easy to pull, very intuitive, and had a second locking feature with the sleeve. The "hook with rotation and worm gear" in conjunction with the "key mechanism" worked smoothly but required a separate key of which our sponsor JumpSport is not fond. The "three pin with slot" mechanism was a challenge to construct and would likely prove challenging to make internal to a rod. The "tension spring pin" was also a challenge to construct because of its many loose parts, some of which are small and can be easily lost. The "lock slot" did not have an appropriate technique to combine with in order to make it an option. The "toggle clamp" proved to require a large amount of force. This would be a challenge for young children of a minimum age of 7 (who are our design criteria) and would be especially difficult when raised significantly above ground. After consulting with JumpSport, the "hook with power screw" design and "cross tweezer clamps with power screw" were chosen. One problem that we faced while further examining the power screw sleeve is the potential for accidental unwind. In order to negate this problem, a button was included that will snap up into the sleeve when the screw is fully tightened. This has a few advantages. First, it prevents the screw from unwinding, as mentioned above, and it also gives the user the assurance that the sleeve is fully screwed down. This is important for young children who may not know just how much they should be tightening these sleeves. This visual aid will allow the user to have consistently secure connections.

In addition to the connection rings on the balls and the connectors themselves, we considered an additional restraint for stability. The balls will have the tendency to roll out once weight is applied to either the ball or a connecting rod. If two balls are joined by a connection rod and weight is applied (i.e. someone stands on the rod), the balls will roll to the point where the rod moves to the ground as shown in Figure 5. To prevent this, we considered multiple ways to add an additional restraint. We considered straps so that the user could tie the balls together using the loops on the balls. If straps were used, a single length would be necessary. This limits the potential of not tightening or placing the straps improperly. The connection would be similar to a hook like the connecting rods have but would stretch so that the strap would still be somewhat taut. A tightening system like a ratchet was also considered, but ratchets tend to require a lot of force toward the end which we believe would not be conducive to a 7 year old whom we are designing toward. Though straps would add the restraint necessary to prevent the unwanted motion, it would also pose as a potential tripping hazard. If the user is jumping on the balls and falls, he or she is less likely to be aware of the surroundings and could trip over the straps. In addition, these straps have the potential to limit the number of ways the balls could be configured and might be more readily misused or not used at all if the original configuration cannot be easily constructed with the straps.

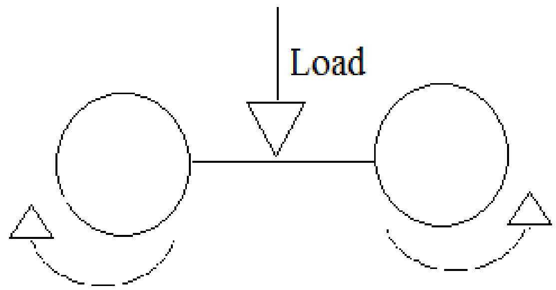


Figure 7 Potential deflection of the ball when weight is applied. The rod will roll to the ground.

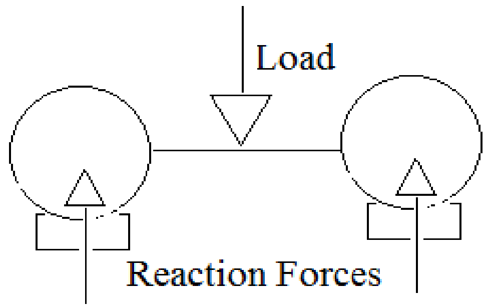


Figure 8 A base beneath each ball will eliminate the potential of rolling to the ground.

Rather than straps, we decided individual stands would add the stability necessary while eliminating the problems discussed with straps as shown in Figure 6. A ball stand would only be necessary for the balls at the base of the structure. The stand adds the necessary contact area between the ball and the ground to add stability. An example of such a stand is pictured in Figure 7.

Figure 9 Ball stand design. Reference: https://www.wolverinesports.com/images/products/GE686P.JPG

In terms of manufacturing, both the "cross tweezer clamps with power screw" and "hook with power screw" ideas are simple. The sleeve which covers the power screw can be injection molded, as can be the molded plastic base. Though the initial price of a mold for such a process is high, the mold lasts through multiple production cycles and the process itself is relatively low priced. The power screw and hook can be purchased as individual components for the prototype and cast for actual production. The button can be purchased in large quantities, pre-manufactured.

Going from concept to reality required us to make several changes and additions to the original idea in the hook, sleeve, short rod length, button, loop locations, and the addition of a ball stand.

Dr. Widmann showed us that welding a hook onto a shaft (our initial idea) is a bad idea as it is not structurally sound. A better idea is to screw the hook into the power screw component of the rod for better structural integrity. The screw (item 9587T23) can be purchased on McMaster-Carr for $8.52.

We broke the sleeve into two parts. We wanted metal on metal threads when connecting the power screw to the sleeve, so we created a metal hexagonally shaped part (shown in yellow below). The hex would then be press-fit into the sleeve (the transparent piece below), which has a hexagonal hole. The purpose of the hexagonal shape is to prevent slipping when the sleeve is rotating. Additionally, one side of the hex piece is circular to connect to the plunger as the original sleeve was designed.

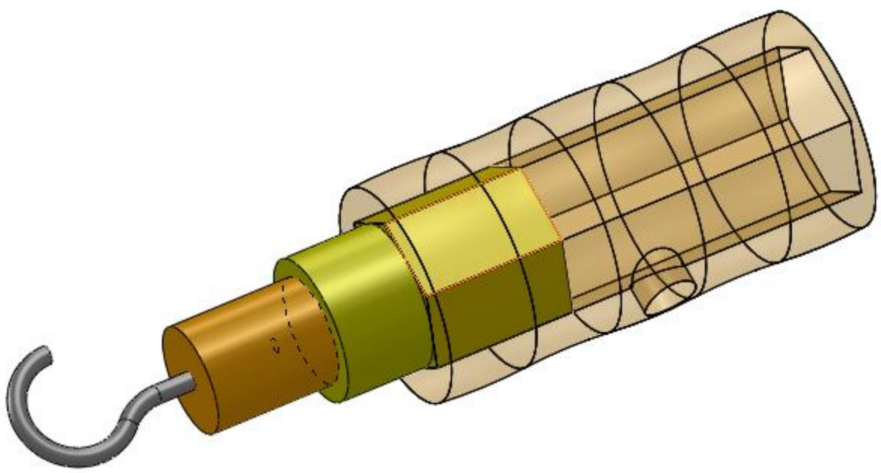


Figure 10. Revised Sleeve with Hex

For our prototype, we are going to purchase a hex nut and simply machine the cylindrical portion to our specifications.

The length of the small rod was changed. Our initial design, shown in Figure 9, was too long. JumpSport wanted us to make the ball-to-ball connectors as short as possible. We thought that the ball-to-ball connector should still be big enough to fit your foot onto as a climbing aid, and JumpSport agrees. We then shortened the rod length to 1.5 average hand lengths: a length we thought was appropriately long enough onto which a grown person can comfortably put his or her foot. The revised rod is shown in Figure 10.

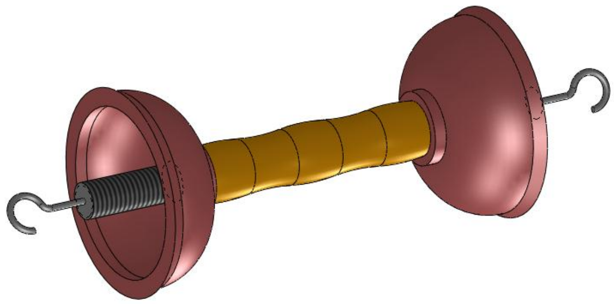


Figure 11. Original Shrot Rod

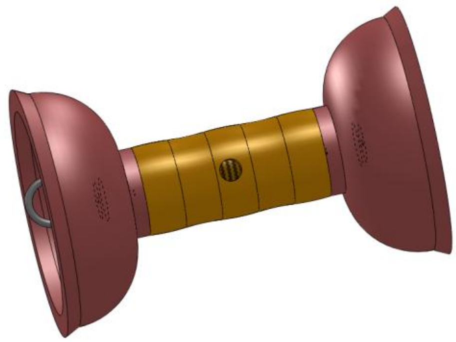


Figure 12. Revised Shrot Rod

The button design is not yet complete. We realized that our initial button design would not work for the short rod and we want the button to operate the same way for both the ball-to-ball connector and the ball-to-rod connector. We have decided to pursue a design in which the button is on a spring placed internally to the power screw. The hole for the spring will be cut radially, allowing the button to pop up once it reaches the hole when it is screwed tight enough.

Creating the ideal loop locations required a brainstorming session. After drawing different configurations and considering different geometries, we decided that the basic cubic and tetrahedral formations were ideal for allowing lots of creativity without too much cost. Using these shapes as basic formations, more advanced formations can be made, such as a hexagonal structure shown in Figure 13.

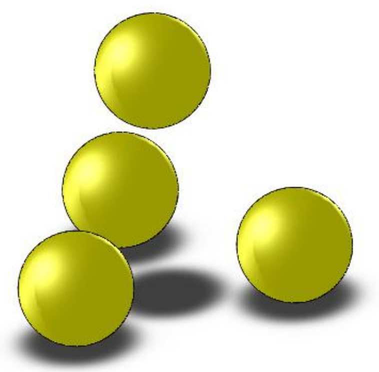


Figure 13. Tetrahedral Formation

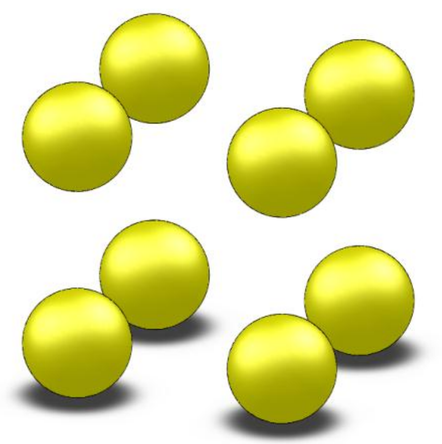


Figure 14. Cubic Formation

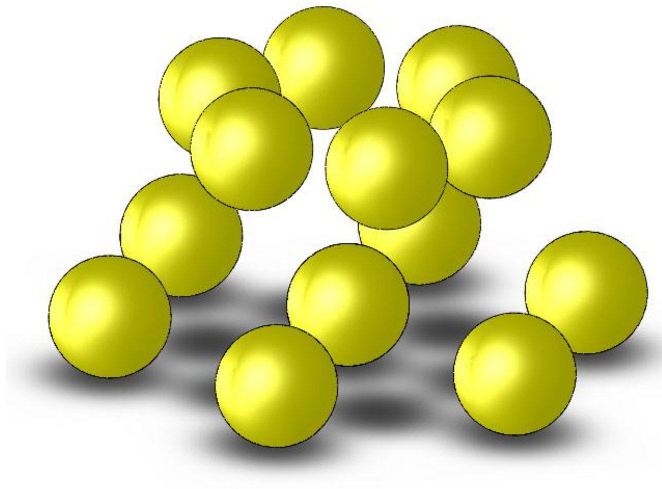


Figure 15. Hexagonal Formation

There are loops rotated around the North-South on the horizontal and 60° above and below the horizontal, as well as at the North and South poles. In "rows" of loops placed 60° from the horizontal, the loops are placed every 60° all the way around. The loops along the equator are placed every 30° rather than 60°. This allows the creation of both the cubic and tetrahedral base shapes as previously mentioned. We can place more loops along the equator than 60° from the horizontal for two reasons. First, they do not require additional mold pieces due to their location. Secondly, when they are every 30° for the ones 60° from the horizontal, the loops interfere with the plunger if a rod is connected to any of them. The new ball can be viewed below in Figure 11.

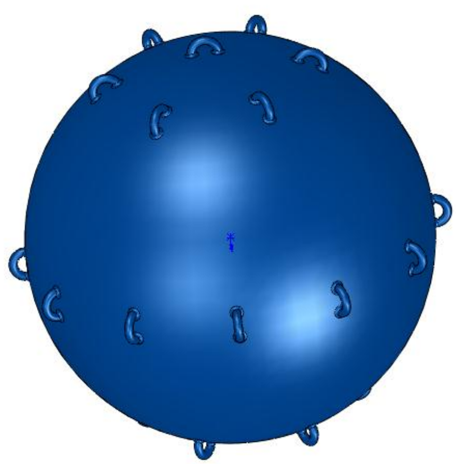


Figure 16. Ball with Loops

For our purposes, we will produce a scaled down model of the complete product. We intend to have the injection molding, the rotary molding, and any necessary construction and assembly conducted on campus using campus facilities when possible. Otherwise, we intend to contract work to the appropriate companies. We are in the process of ordering the necessary processes and obtaining an estimate for a complete prototype. For prototyping purposes and cost efficiency, there is also the option to machine the, would be molded, parts. All machining can be conducted on campus without the need to contract an individual or company. All other parts such as the power screw, rod, button and hook will be purchased from McMaster Carr for approximately $300.

Analysis

We carried out calculations on the most critical parts of the power screw design. These critical portions include the rod itself for the rod connection and the loop on the ball when the hook is causing pure tensile loading and pure shear loading.

Both torsion shear deformation and bending calculations were conducted on the rod. From these calculations, we decided to have a thin walled steel tube be the rod for the ball to rod connection. With standard steel tubing of size 1.5 inch outer diameter and a thickness of 0.035 inches, the torsional rotation is 0.03 radians (this is very small) when a 50 foot pound torque is applied. We believe a 50 foot pound torque is well above what the rod will actually experience. The only torque the rod will experience after assembly is when someone steps on the rod and slips. Torque will be applied to the rod up until the static friction is changed to dynamic friction. Bending is a larger concern for the rod. Two scenarios were considered, a distributed load of 500 pounds along a 3.9 foot long rod and a point load of 500 pounds applied at the center of the 3.9 foot long rod (Figure 8). We decided a maximum bending deflection for the rod at these given loads to be 0.10 feet or approximately 1 inch (again, these loads are higher than what the actual product will be experiencing). The resulting bending deflections with the chosen rod are 0.55 inches for a distributed load and 0.87 inches for a point load. We believe 0.10 feet of deflection is acceptable because these calculations are worse case scenarios and do not take the energy the ball is absorbing on either side of the rod into consideration. Rather, both ends of these rods as calculated have static pin connections.

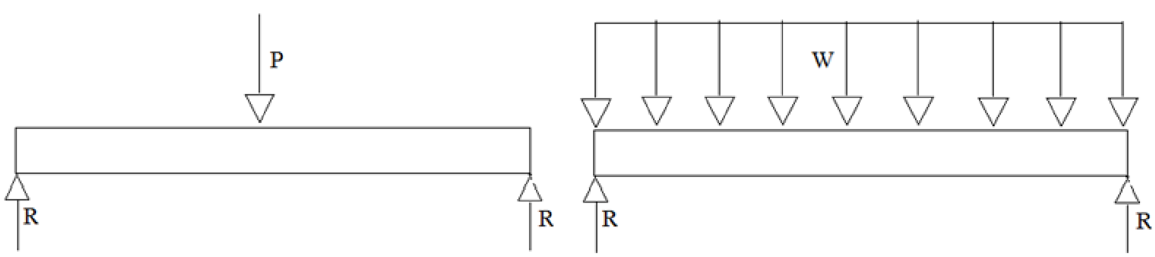


Figure 17 These are diagrams of the bending rod calculations. On the left, P is 500 pounds for a rod length of 3.9 feet. On the right, W is a 500 pound distributed load across a 3.9 foot long rod (10.5 pounds per foot).

The loop thickness is also a critical dimension and point of our design. If, at any point during the use of the product the hook of the connection were to apply pure tension to the loop (very unlikely but again is a worse case scenario), the loop cannot be the weakest factor. Figure 9 explains the curved analysis of the loop with an applied tensile force. It is preferred that if the loop breaks, it breaks along the ball without ripping the inflated portion of the ball. We decided this would be the safest failure mode because the user would know the product is broken without having the ball burst. In addition, if the product is in use when it breaks, the user can visually see the break point even when a connection is attached. This not only promotes safety but also encourages the user to simply replace the product rather than trying to 'fix' the loop by inappropriate measures such as tape. The loop under pure tension at the thinest point deflects 0.008 inches when 500 pounds of force are applied. This is very little deflection and is well within the plastic region of the material.

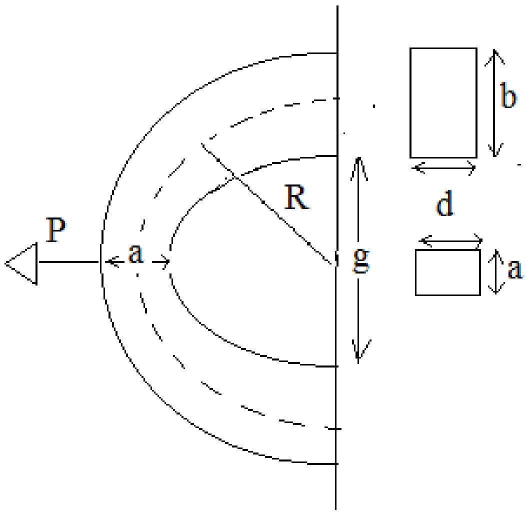


Figure 18 This is a representation of pure tensile force applied to the weakest point of the loop. The complete calculation is available in Appendix C.

Shear is also a large concern for the loop. As mentioned, it is ideal that the failure mode be at the end of the loop without ripping the inflated portion of the ball. Unfortunately, more exact information on the properities of our chosen plastic (a type of plasticized PVC similar to the Mondo ball datum) are required. We intend to gain this information through tensile tests and experimentation so as to ensure this design feature.

Construction

The next steps in the project are constructing and testing a series of variables to ensure we meet all the customer and engineering requirements. As mentioned, we intend to fulfill as many processes on campus as possible. Currently, we are still finalizing the procedures including the mold machining, injection molding, and rotary molding. Our goal is to produce a scaled prototype of the entire design. This entails what would come in a single package for the consumer to purchase-10 balls, 12 rods, and 12 short connectors.

Table 5 Parts list for Small Scale Prototype

		Part:	Number per Rod:	McMaster-Carr Part Number:	Cost:
Long Rod	1	0.315inX6ft Steel Rod Alloy 4130	1	89955K23	$22.15
	2	¼”–20 Threaded Turnbuckle Hook (right)	2	3022T869	$2.69
Small Rod	1	¼”–20 Threaded Turnbuckle Hook (left)	1	3022T862	$2.69
	2	¼”–20 Threaded Turnbuckle Hook (right)	1	3022T869	$2.69
Sleeve	1	¼”–20 Zinc-Plated Grade 2 Hex (right)	2	90264A435	$0.19
	2	¼”–20 Zinc-Plated Grade 2 Hex (left)	1	N/A	N/A

Table 6 Parts list for Full Scale Prototype

		Part:	Number per Rod:	McMaster-Carr Part Number:	Cost:
Long Rod	1	1.5inX6ft Steel Rod Alloy 4130	1	89955K38	$46.16
	2	1– ½”–4 Threaded Rod 12” (right)	1	98941A770	$38.92
	3	1/4"-20 Diameter Hook 10 pack	1	9491T14	$5.61
Small Rod	1	1– ½”–4 Threaded Rod 12” (right)	1	98941A770	$38.92
	2	1– ½”–4 Threaded Rod 36” (left)	1	98935A549	$54.62
Sleeve	1	1– ½”–4 Steel Hex 3 ½” Ht. (right)	2	93023A674	$59.29
	2	1– ½”–4 Steel Hex 3 ½” Ht. (left)	1	93026A300	$59.29
	3	2 7/8” aluminum round stock 1ft Alloy 2024	1	86985K242	$115.93
Plunger	1	7” aluminum round stock 3in Alloy 6061	1	1610T63	$83.99

We have decided to go with a large scale prototype instead of the small scale prototype for a few reasons. First of all, a small scale prototype would require us to rotary mold smaller balls to test our models upon. In the case of the full scale model, we can use the Mondo balls to test our prototype rods. Second of all, a full scale model will be easier to manufacture out of round stock plastic rather than injection molding the parts. Injection molding would be required for full scale production, but the costs are too high for our prototypes. To be more specific, instead of actually machining a mold, which would be difficult and costly, instead we will machine one part of both the sleeve and plunger out of Aluminum, and then we will use an at home molding material to make multiple pieces. We will have to individually buy the rods and power screws, but this cost will not be too great. As for the creation of the balls, we will purchase 75cm exercise balls and glue loops in the desired locations. This will not be structurally strong enough to hold the required weight, but it will give us a good visual model of how the product will look; it will also provide a product that can be ergonomically tested for assembly and disassembly time for different age groups. The actual products that we will create are shown in Table 7 below.

Table 7 Prototype Production Chart

Prototype Part Number	Part Name	Corresponding Production Part Number	Number produced
BBP1	Long Connector	BB21	12
BBP2	Short Connector	BB22	12
BBP3	Ball	BB05	10

Product Realization

To construct and assemble a full scale model, we decided to machine original pieces and use an at home molding process to mass produce the parts in plastic. The machining, as predicted, was time consuming but provided us with a good start as the molding was very easy. The sleeve was lathed from 2 7/8 inch diameter aluminum rod stock as shown in Figure 19.

Figure 19 Sleeve on lathe after mill work had been completed

The plunger portion was also lathed from seven inch diameter aluminum rod stock. The sleeve, even with multiple contours was very easy to machine. The plunger on the other hand, required machining on both the inside and outside diameters. In Figure 20, the inside diameter is being cut after the outside had been cut. This order of operations was necessary in order to have enough material to put in the chuck. There was a large amount of vibration between the cutting tool and the stock which made it a challenge to machine. Although the finish was not as nice as the sleeve, there was no negative effect on the plastic molds or parts. The sleeve also required mill work to cut the hex on one side. This was done prior to the lathe work as the rod stock is easier to grip on to compared to the contoured sleeve. The inserts were also milled.

Figure 20 Plunger after outside diameter had been lathed and while machining the inside diameter

We purchased two inch long acme thread nuts and machined one inch to the cylinder required to fit into the plunger piece. As these inserts were steel, the machining was time consuming but the parts came out accurate and consistent. Finally, we cut six foot steel tubing down to size (three feet) for the long rod and cut the acme thread screws to the appropriate length as well.

All of the above listed parts (except the steel rod) we produced molds from in order to make multiple parts in plastic. Our molding attempts were two fold. Originally, we used a strong epoxy (Duromax from Smooth-On) which proved problematic and cost us a large amount of time. The epoxy, even when release spray was heavily used, did not detach from our original parts. The one exception was the outside plunger portion as seen in Figure 21.

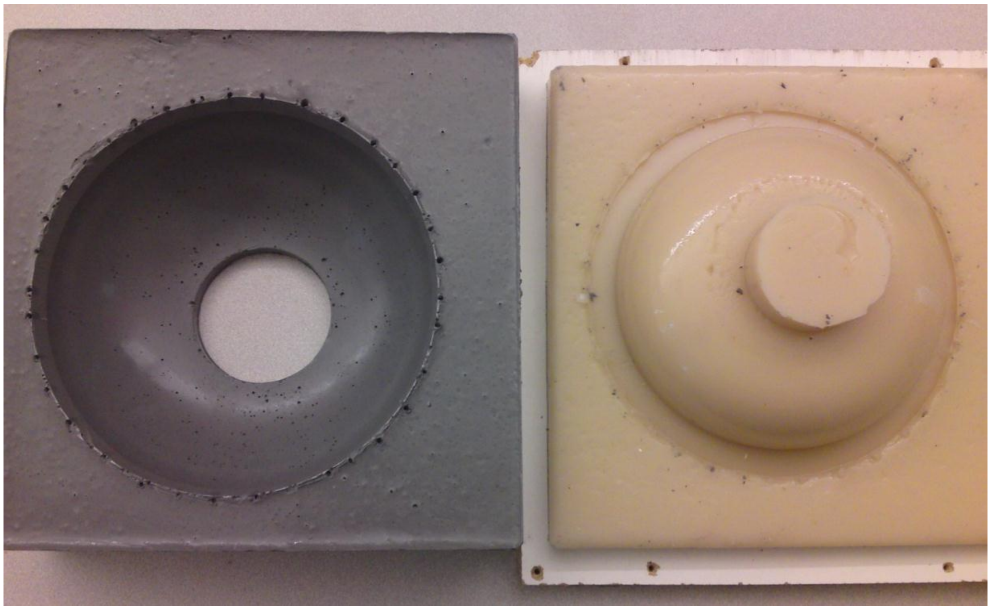


Figure 21 Mold for Plunger, shows both the Duromax epoxy and Vytaflex

After breaking off the epoxy chunks, we tried a much more forgiving and flexible molding material called Vytaflex from Reynolds Advanced Materials. Figure 21 shows both the gray Duromax epoxy adjacent to the Vytaflex. This was much more conducive for our purpose. We were able to make all of our necessary molds including molds for loops to glue to exercise balls (Figure 22) and produce our plastic parts using Task 7 from Reynolds Advanced Materials. We produced 6 long rods with connectors on each end, one small rod connector, and 4 balls with loops to create a tetrahedron.

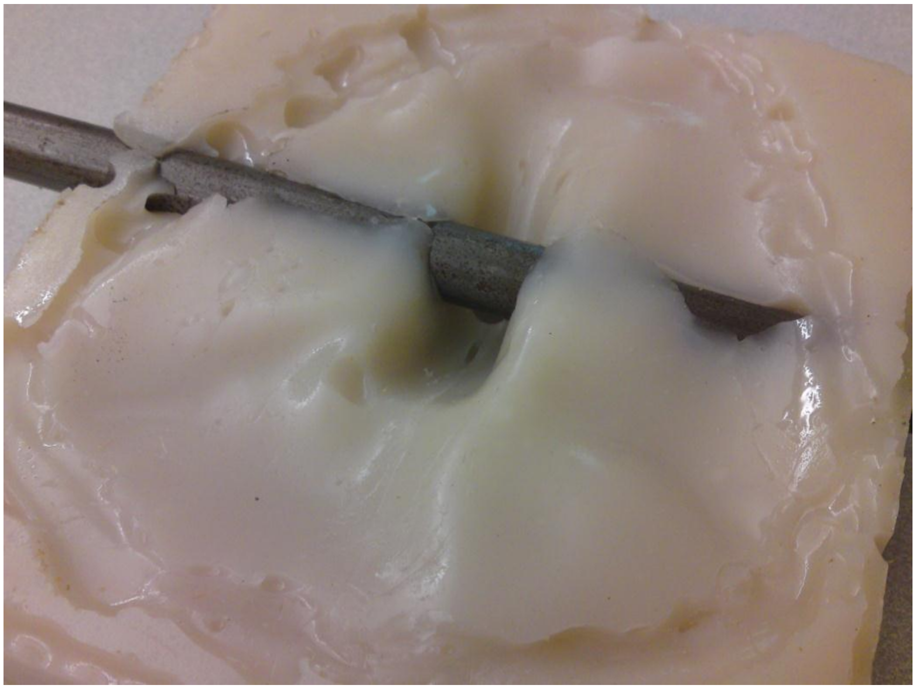


Figure 22 Mold for the loops

Originally, we had planned on keeping the acme screw and insert as steel parts. We realized, once these parts had arrived, that plastic would be safer as is it is lighter and will not hurt an individual if dropped on the foot, children at play hit or throw it, etc. In addition to increased safety, our structural integrity is not lost by using plastic rather than steel. Lastly, it will be less expensive to mass produce these parts in plastic. A picture of the finished assembly is shown in Figure 23.

Figure 23 Fully assembled connector

We found, it is very important to use a heavy duty silicone release spray when making both the molds and the parts from the molds. It is nearly impossible to extract the original parts without using a silicone mold release. Even attempts with other release sprays proved useless.

Design Verification Plan

This project requires two periods of testing, first to find the appropriate plastic properties and second, to ensure we have fulfilled the customer requirements with our prototype and design. To find the plastic properties, we will test the hardness and tensile strength on multiple Mondo balls and compare those results with other available hippity-hop plastics (Mondo offers the thickest PVC). This procedure requires that we construct a tool to hold the ball so that a tensile machine can be loaded correctly to run the tests. The second series of tests will be performed after the prototype is constructed. We intend to test the hardness of the plastic, loads the loop can withstand, the surface temperature of the ball after a given amount of heat exposure, weight capacity of the ball, deflection of the ball under a specified load, the effectiveness of the ball base/stand, assembly time, disassembly time, and lastly the approximate packaging size. Multiple trails will be conducted for each type of test. A detailed listing of the verification plan is available in Appendix D.

Tensile Testing

We conducted multiple tests to find the material properties of the Mondo Ball plastic. To begin, we used a fish scale to gain basic load information (Figure 24). This test helped us chose an appropriate maximum load when we would use the Instron Tensile Machine and purchase appropriately rated items to construct the holding rig for the Instron. We measured a load of approximately 120 pounds resulted in a total of a half inch deflection. Thus, we made our maximum load for testing 500 pounds and ensured all the rig material was appropriately rated.

Figure 24 Initial tensile test using a big fish scale

When using the Instron, we conducted three types of test. First, we ran a pure tension test. The weakest point of the loop is the midpoint, therefore this tension test would pull similar to the fish scale test (Figure 25). In this Figure, the ball is held stationary from the bottom by a steel clamp just like the steel clamp shown in the photo. Both clamps are attached to the ball by a bolt assembly, on the top it is directly attached to the loop and is the test point simulating the hook of the actual design. On the bottom, the bolt assembly attaches to the webbing which is wrapped around the ball and isolates the movement of the upper clamp and loop from the rest of the ball. The maximum load withheld during this tensile test was approximately 180 pounds. Though this is less than expected, we assume by increasing the thickness of the loop, the maximum load would increase. A test was conducted to obtain Young's Modulus of Elasticity for the material discussed later.

Figure 25 Tensile test using the Instron

In a similar fashion, we tested the second weak point of the loop, the loop in shear. This test is a worst case scenario. The only way we could only the ball and get results was to test what is called the "dual shear" of the loop. In this test, the loop was tested in both directions simultaneously as seen in Figure26. In the actual application, only one point of shear would occur because there is only one hook. The maximum load withheld for the double shear test was approximately 160 pounds. Again, this is worse case scenario. In actuality, this load can be most likely nearly doubled since it will experience single shear.

Figure 26 Shear test using the Instron

Our last test with the Instron was strictly to obtain Young's Modulus of Elasticity while the others were for maximum loads under specific circumstances. To obtain Young's Modulus we used an elastometer to measure the deflection while a strip of the Mondo Ball plastic was tensioned as in Figure 27.

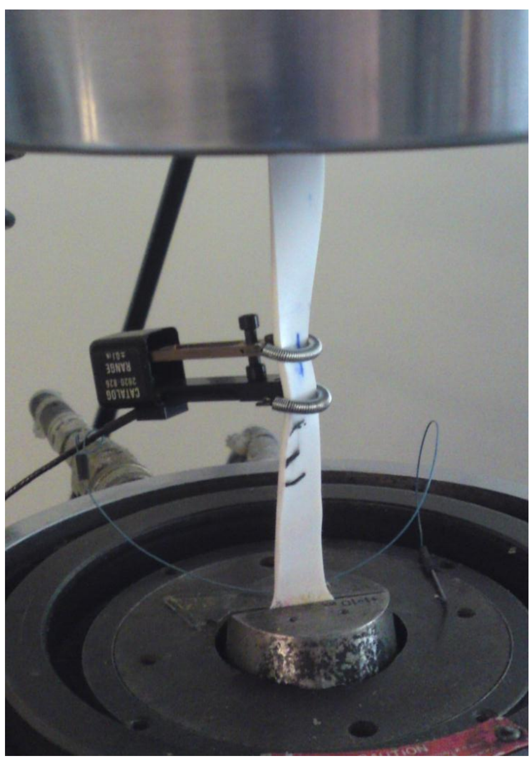


Figure 27 Individual strip test using the Instron and an extensometer

With this test we were able to create a stress strain curve, seen in Figure 28, and used the slope to find the Young's Modulus of Elasticity of 1120 psi. From our initial calculations, this modulus value proved correct as we received the same amount of deflection as we calculated.

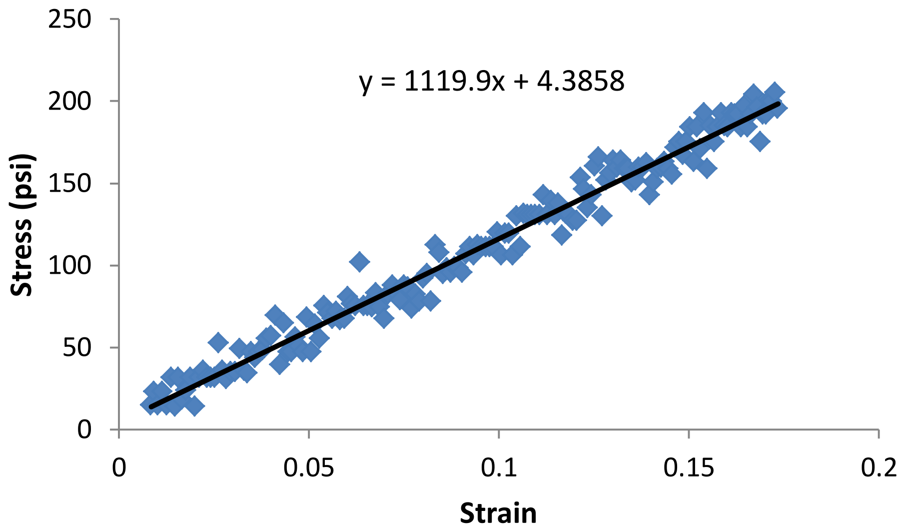


Figure 28 Stress vs. Strain curve for the individual strips

Hardware Testing

Once construction was completed, loops were adhered to our exercise balls to use as visual representations of what the final product will look like. A plastic epoxy was used to glue the loops because it proved strongest in our tests. However, once the structure was assembled, the large shear loads from the rods as well as the bending moments cause the epoxy to fail, see Figure 29. Although this was always a possibility, we hoped that the 60 lbs of tensile strength the epoxy held in testing would be sufficient to hold the structure together. Since the loops did fail so quickly, some tests were not able to be completed. The load tests on the rod and balls while the structure was assembled was not completed, and substituting the Mondo balls in for the test did not bring useful results because of the size differences between the rods and the balls. The ball stand test was also not able to be tested fully; however, the ball stands did drastically reduce the loads on the loops and allowed for some connections to be made without failure. This in itself does not prove the ability of the stands but it is promising.

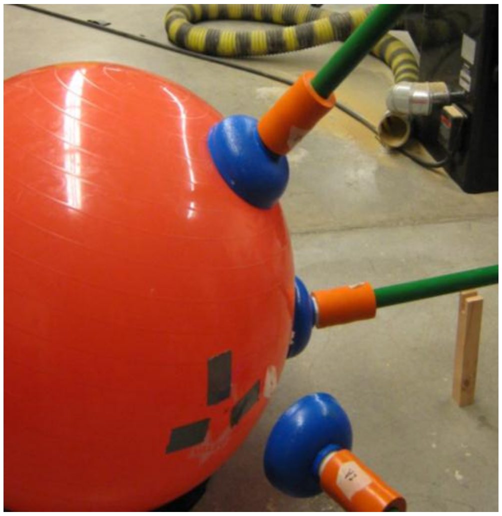


Figure 29 Close up of loop failure

Because the structure could not be fully assembled, ergonomic time testing could not be completed; however, useful information was attained from the testing. The use of the power screw allowed for simple connections, and connecting multiple balls at once was not strenuous. This was a reason for concern because screwing multiple screws a few inches each could have cause fatigue, which could lead to improper connections, yet our results show that this should not be of concern. Although construction did not go as planned due to the loops failing, while holding the balls in place with most of the rods connected did give us an idea of the final product, see Figure 30. From this we determined that this product would be fun to play on and seemed to be of appropriate size to be able to climb on, in, and around.

Figure 30 Constructed tetrahedral configuration

One large concern did arise from the ergonomic testing. Connecting a suspended ball was difficult for 2 adults due to the weight and awkwardness of the ball, see Figure 31. There is no way that a child of 7 years old could connect a suspended ball by themselves, and it would be extremely difficult for a group of 7 year olds. Parental help would be required for a structure of this size. However, the ball to ball connections could be completed by a smaller child because the ball will not be so far off of the ground.

Figure 31 Steve supporting suspended ball with his head during construction

Conclusions and Recommendations

The project finished on schedule with the following products as deliverables for the Sr. Design Expo on June 2nd. The main display table will contain a technical poster that will cover our design. Also at our display table, we will have one small connector that will be testable on two of the Mondo Balls. The second part of our display will be the full size model. This will consist of a four ball tetrahedral configuration using six long connectors. The model will be semi-functional, the top ball will not be able to be connected to the lower balls due to the inability of the loops to hold the required loading, but the connectors will be fully functional. There was also insufficient time to mold enough loops to cover each ball completely, so the exercise balls will only have loops in the locations required for the tetrahedral configuration.

Due to the outcome of the products that we made, we have a few recommendations. However, with every change, there are also negatives that go along with it. Increasing the thickness of the ball and loops would allow for the required loading, but it would also reduce the portability of the unit. This weight increase would also increase the ball to rod weight ratio, which would increase the rotational stability of the structure. However, an increased ball weight would make constructing the structure off of the ground even more difficult, and would be unusable by children alone. Downsizing the whole structure a little bit would make building the structure easier to assemble; however, decreasing the size too much would limit the versatility in which the children can play. Making the rods out of plastic would decrease the weight of the structure, but it would not be as strong. Our final recommendation is that more prototyping and testing with actual materials that will be used needs to be done before a final decision can be made, but as of now this product is not feasible. Also finding a better representation of what the ball and loops will be like would be extremely helpful in making a final decision.

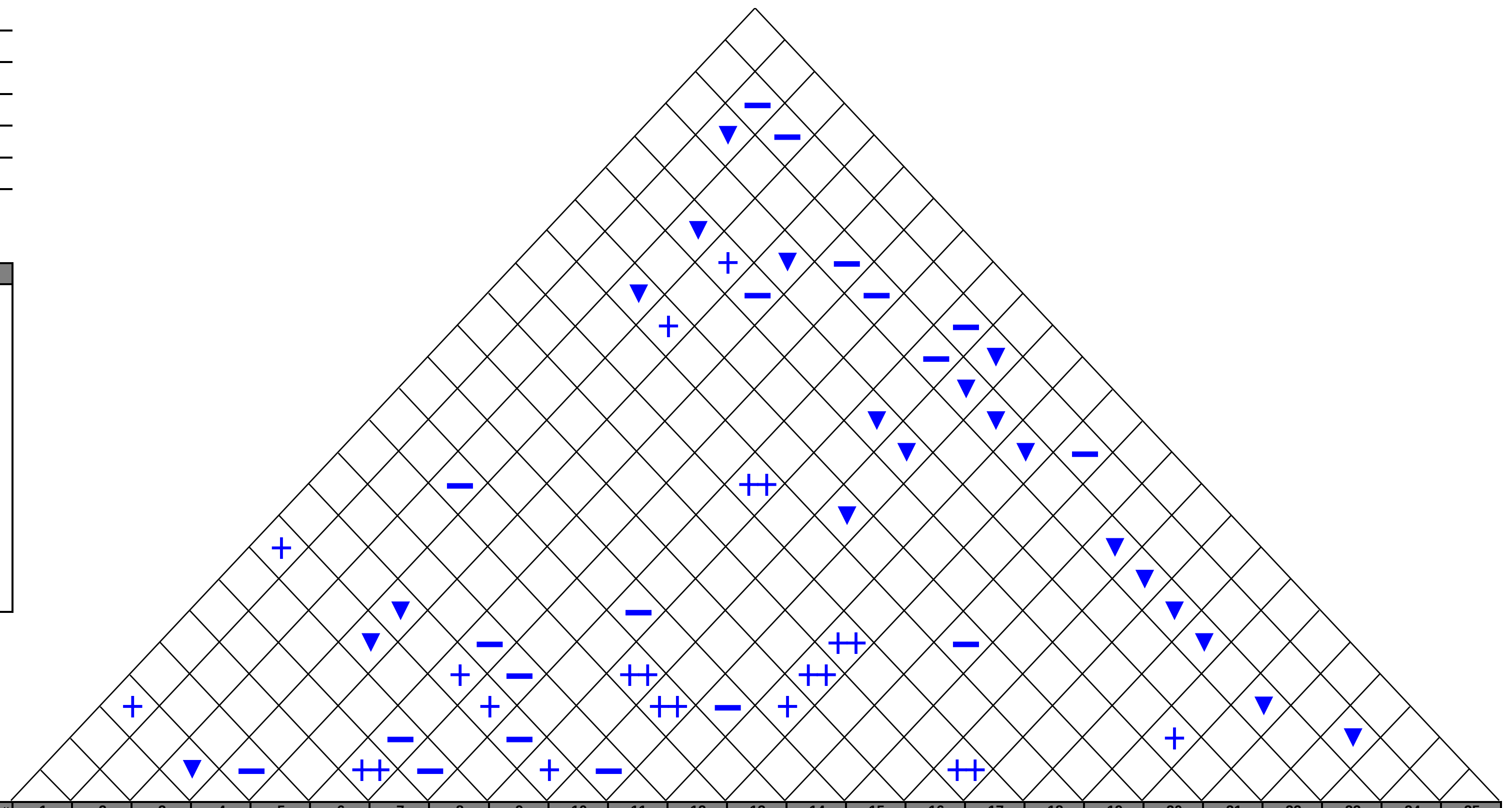
Title: Building Balls

Author: Steve Rose, Rosalie Mangione, Gary Johnson

Date: 10/19/2010

Notes:

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

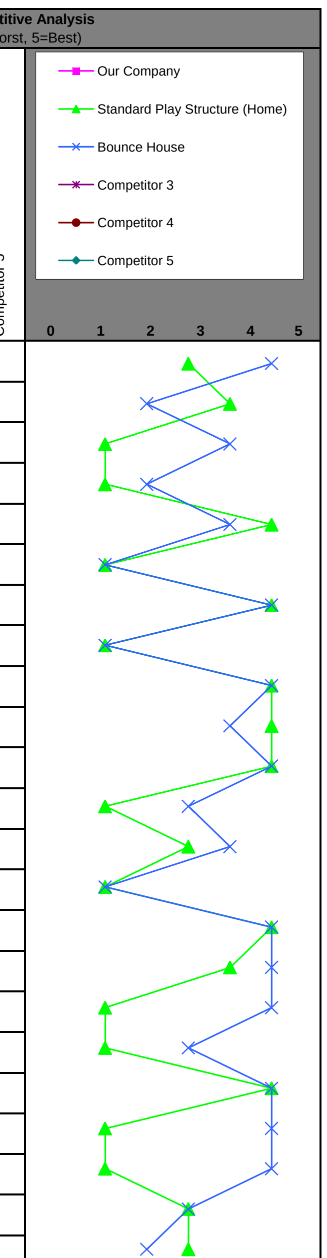


Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")

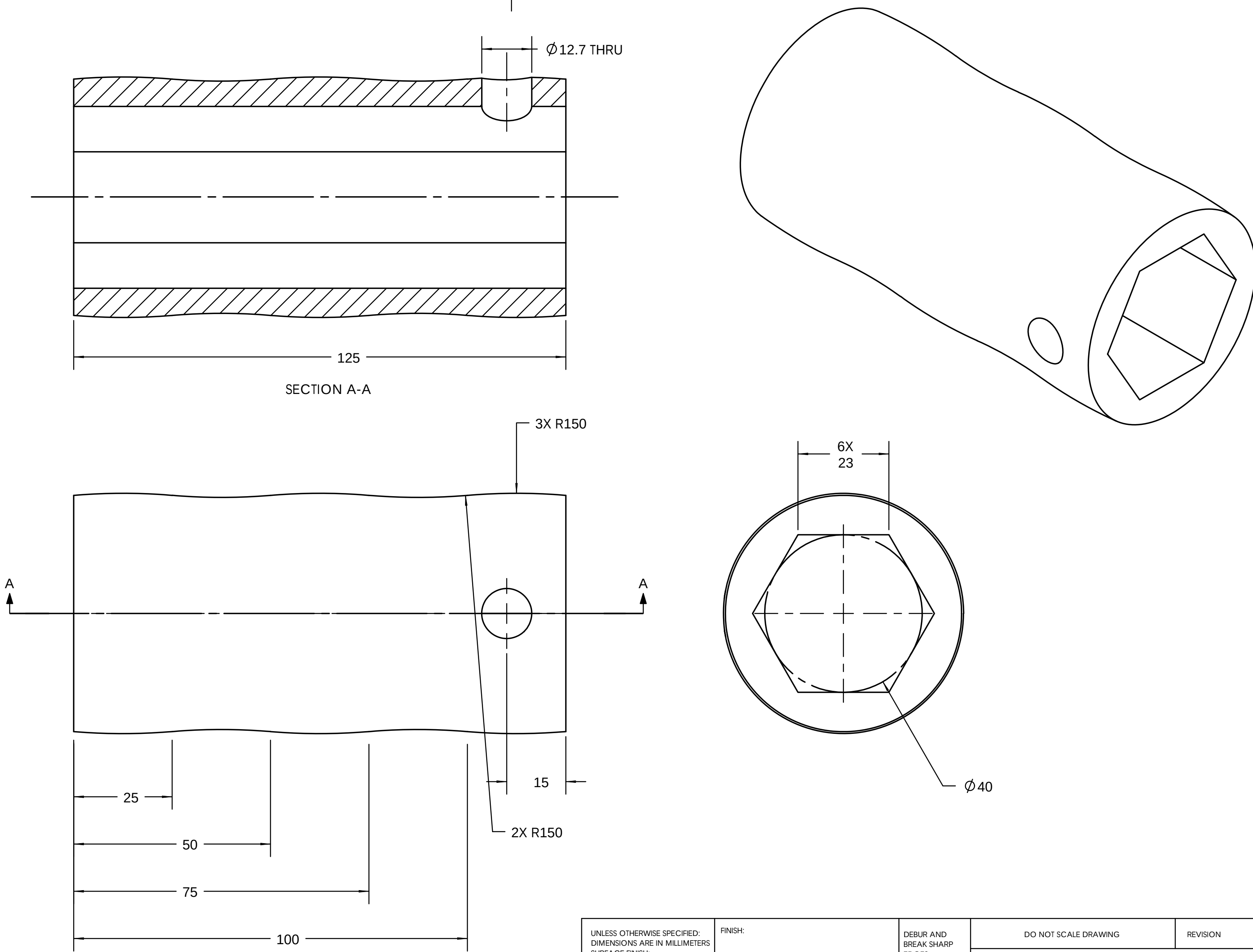
Demanded Quality (a.k.a. "Customer Requirements" or "Whats")

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality	1 Number of Configurations	2 Number of Colors	3 Number of Parts	4 Assembly Time	5 Number of Methods of Connectivity	6 Total Weight Capacity	7 Individual Weight Capacity	8 Buoyancy	9 Space Required	10 Weight	11 Deflection	12 Life Span	13 Packaging Size	14 Percentage of Requirements Met	15 Water Absorption Factor	16 Temperature of Surfaces	17 UV protection	18 Air Pressure	19 Age Limit	20 Hardness Factor	21 Disassembly Time	22 Number of Parts in Mold	23 Material Cost	24 Manufacturing Cost	25	Our Company	Standard Play Structure (Home)	Bounce House	Competitor 3	Competitor 4	Competitor 5
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	x	▼	▼	x	▲	▲	▲	x	▼	▼	▲	▼	x	▼	▼	▲	x	x	x	▼	▼	▼	▼							
1	9	8.7	22.0	Fun	Θ	▲	▲	O		O	Θ	▲	O																		3	5			
2	9	3.6	9.0	Aesthetically pleasing		Θ																									4	2			
3	9	5.6	14.0	Easy to assemble	O		Θ	Θ	Θ					O																	1	4			
4	9	3.2	8.0	Quick to assemble	O		Θ	Θ	Θ					O																	1	2			
5	9	6.0	15.0	Holds the whole family						Θ	Θ	O			Θ								O								5	4			
6	9	0.4	1.0	Floatable								Θ		Θ					Θ												1	1			
7	9	3.2	8.0	Big	▲		Θ						Θ	▲			O														5	5			
8	9	4.4	11.0	Lightweight			O							Θ			▲														1	1			
9	9	1.6	4.0	Colorful		Θ																					O	O			5	5			
10	9	7.5	19.0	Sturdy						Θ	Θ	▲			Θ																5	4			
11	9	6.7	17.0	Durable												Θ			O	O	O										5	5			
12	9	1.6	4.0	Portable			O	Θ	▲				O	Θ			Θ								Θ						1	3			
13	9	8.3	21.0	Safe						Θ	Θ	▲			O			Θ						O							3	4			
14	9	4.4	11.0	Customizable	Θ		O	Θ	O																O						1	1			
15	9	4.4	11.0	Water resistant															Θ												5	5			
16	9	4.8	12.0	Sun resistant																Θ	Θ										4	5			
17	9	7.1	18.0	Inflatable										O			O					Θ		▲							1	5			
18	9	1.2	3.0	Easy to store			O							Θ			Θ								O						1	3			
19	9	5.6	14.0	Age appropriate					O					O									Θ								5	5			
20	9	7.1	18.0	Soft																				Θ							1	5			
21	9	2.8	7.0	Disassemblable			Θ							O											Θ						1	5			
22	9	1.6	4.0	Easy to manufacture																						Θ	Θ	Θ			3	3			
23	9	0.4	1.0	Affordable		Θ	Θ							O			O									Θ	Θ	Θ			3	2			
24																																			
25																																			

Competitive Analysis (0=Worst, 5=Best)



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Target or Limit Value	5	1 per type of connector/ball	minimal	15 min	2	2000 lbs	250 lbs	2000 lbs	200 sqft	5 lbs per ball	0	5 yrs	3 ft x 1 ft x 1 ft	100%	0	<10 dgF + T amb	Reflectivity > .9	psi	7+	Shore A	<15 min	minimal	$1 per ball	$1 per ball	
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	0	0	7	7	0	5	5	8	0	5	4	3	5	7	2	9	9	5	4	2	8	9	4	8	
Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	
Weight / Importance	147.2	58.7	179.0	158.3	109.9	222.6	275.0	46.0	59.5	144.8	146.4	60.7	61.5	75.0	63.1	63.1	63.1	64.3	67.9	96.4	56.0	17.9	22.6	22.6	
Relative Weight	6.5	2.6	7.8	6.9	4.8	9.8	12.1	2.0	2.6	6.3	6.4	2.7	2.7	3.3	2.8	2.8	2.8	2.8	3.0	4.2	2.5	0.8	1.0	1.0	



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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: X ± 1 mm
XX ± 5 mm
XXX ± 10 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

TITLE:

SLEEVE

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:

PVC

WEIGHT:

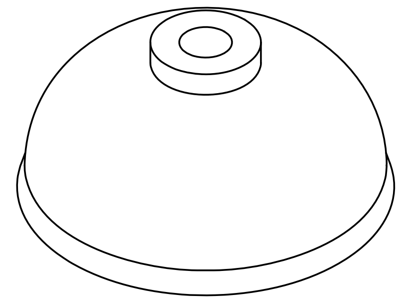
DWG NO.

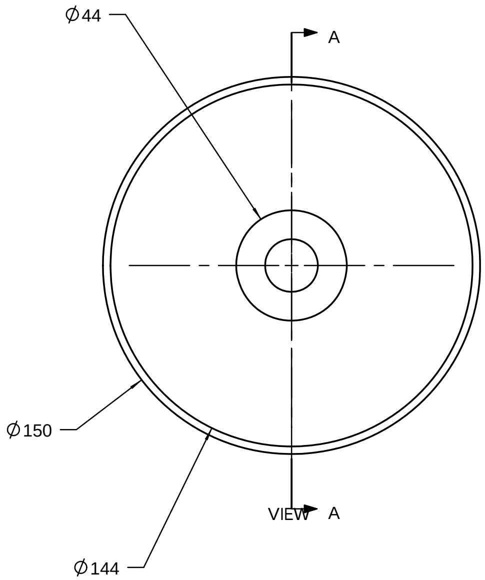
BB01

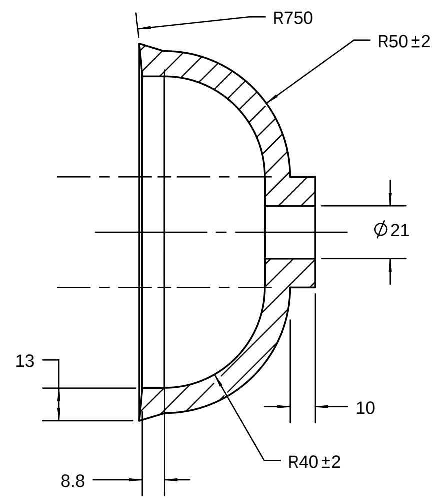
A3

SCALE:1:1

SHEET 1 OF 1







SECTION A-A

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SURFACE FINISH:
TOLERANCES:
LINEAR: X ± 0.5 mm
XX ± 1 mm
XXX ± 2 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

TITLE:

PLUNGER

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:

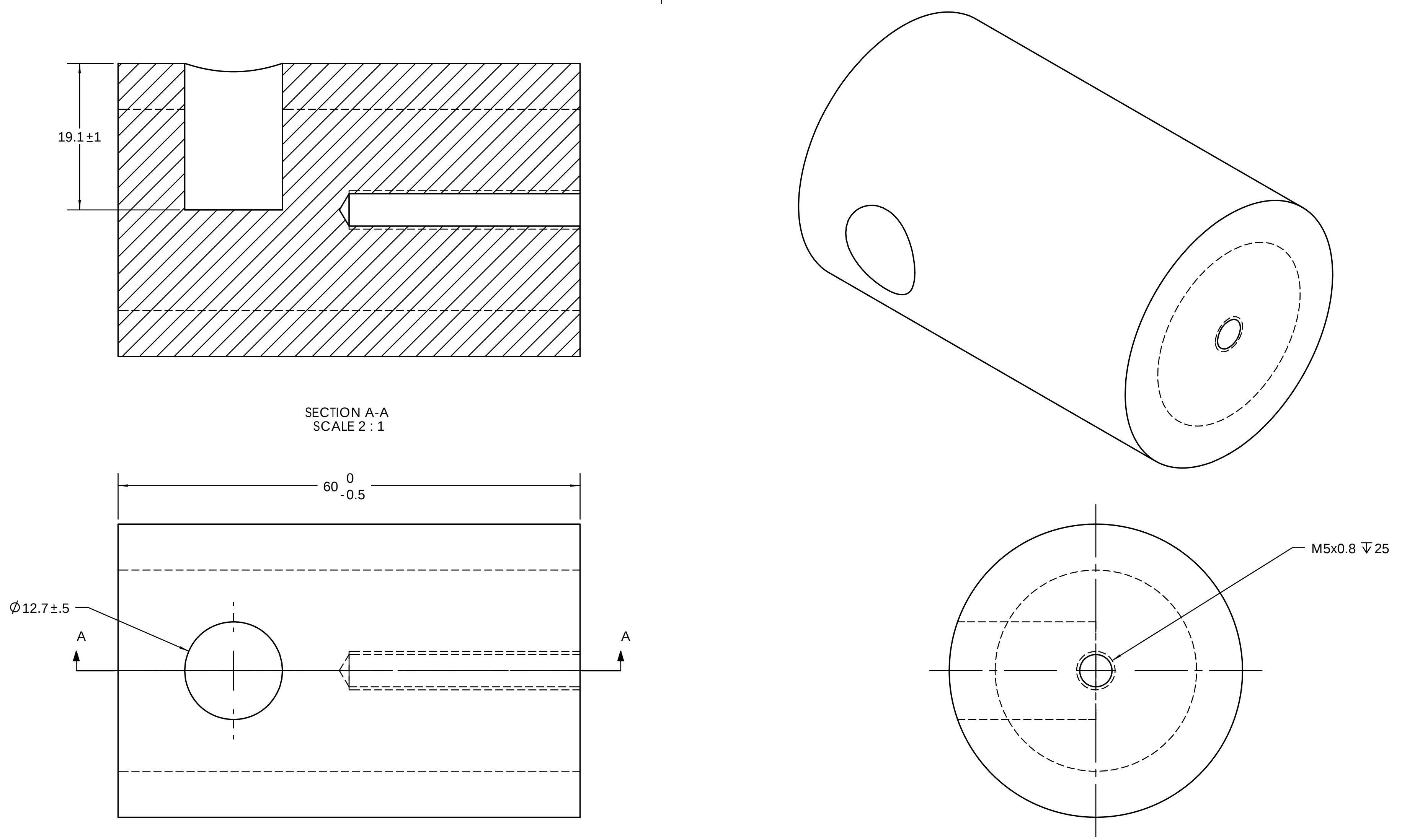
WEIGHT:

DWG NO. **BB02**

A3

SCALE:1:2

SHEET 1 OF 1



NOTES:

- 1-1/2 X 4 BAR STOCK PURCHASED FROM McMASTER-CARR
- DRILL BUTTON HOLE PRIOR TO TAPPED HOLE

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: X ± .5 mm
XX ± 1 mm
XXX ± 2 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:

WEIGHT:

TITLE:

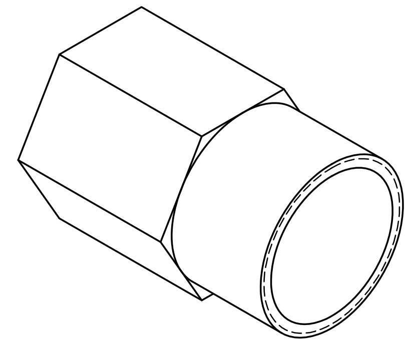
POWER SCREW

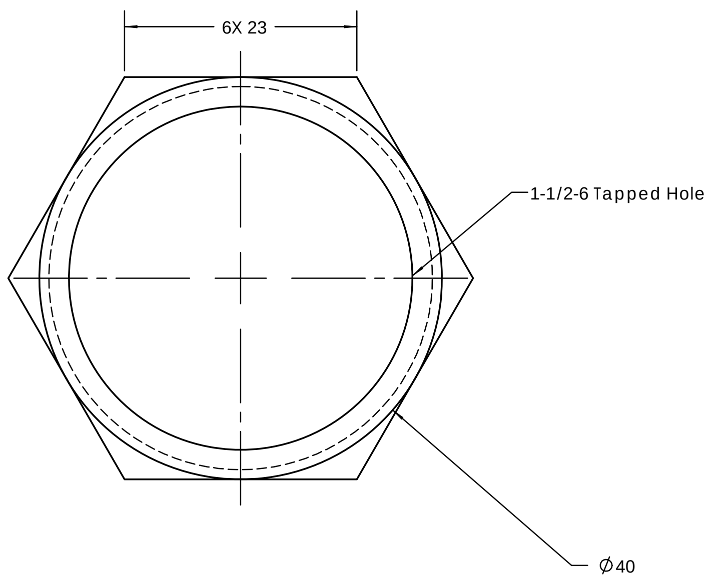
DWG NO. BB03

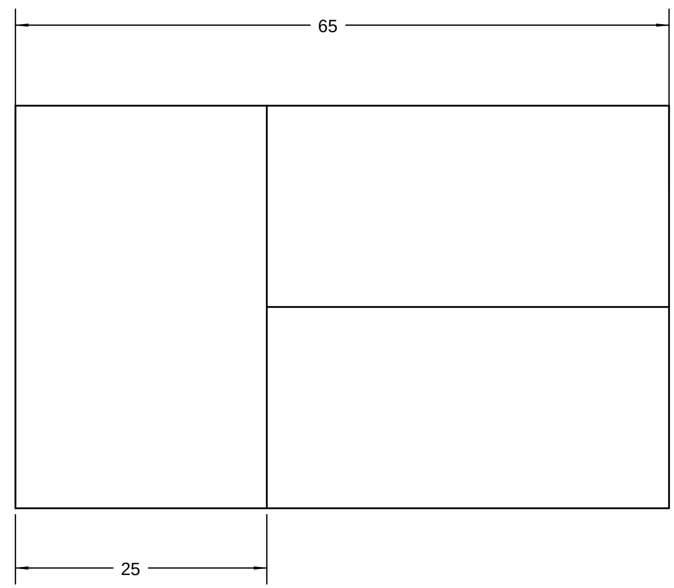
A3

SCALE: 2:1

SHEET 1 OF 1







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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: X ± .5 mm
XX ± 1 mm
XXX ± 2 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

TITLE:

HEX SLEEVE

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:
BRASS

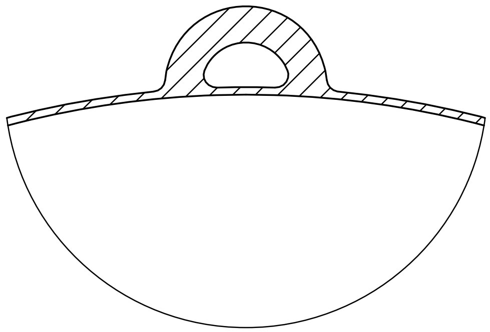
WEIGHT:

DWG NO. BB04

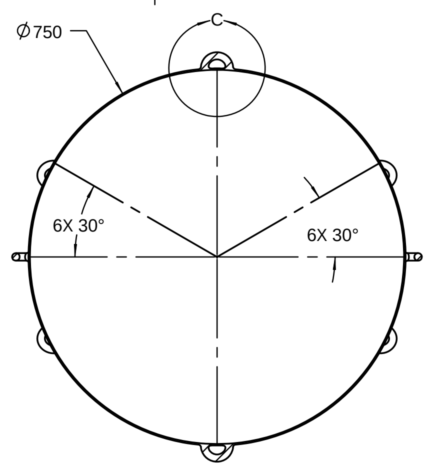
A3

SCALE: 2:1

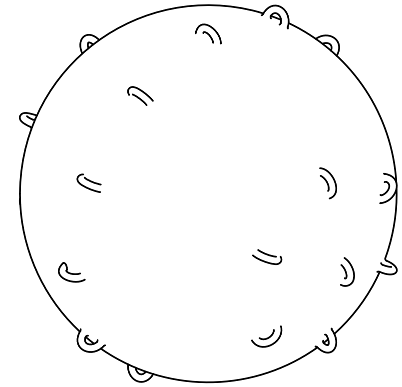
SHEET 1 OF 1

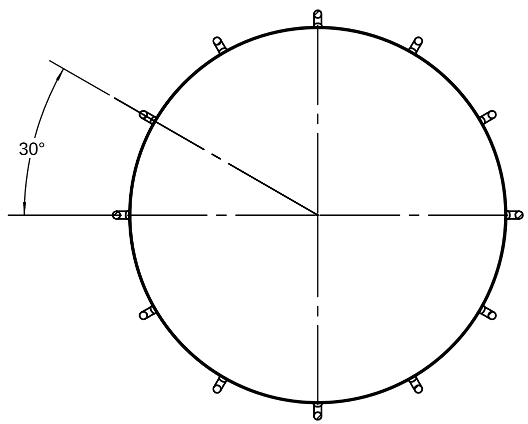


DETAIL C
SCALE 1 : 2

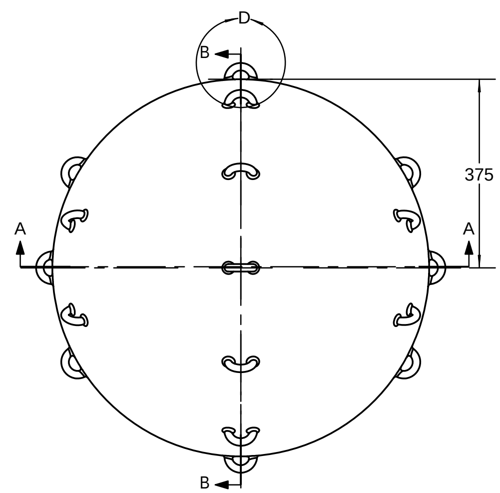


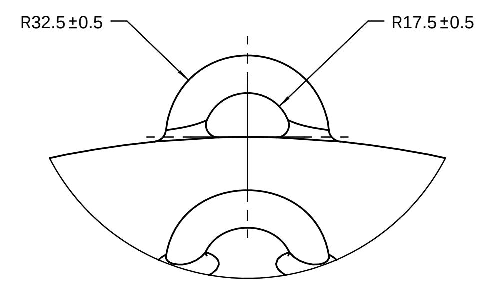
SECTION A-A





SECTION B-B



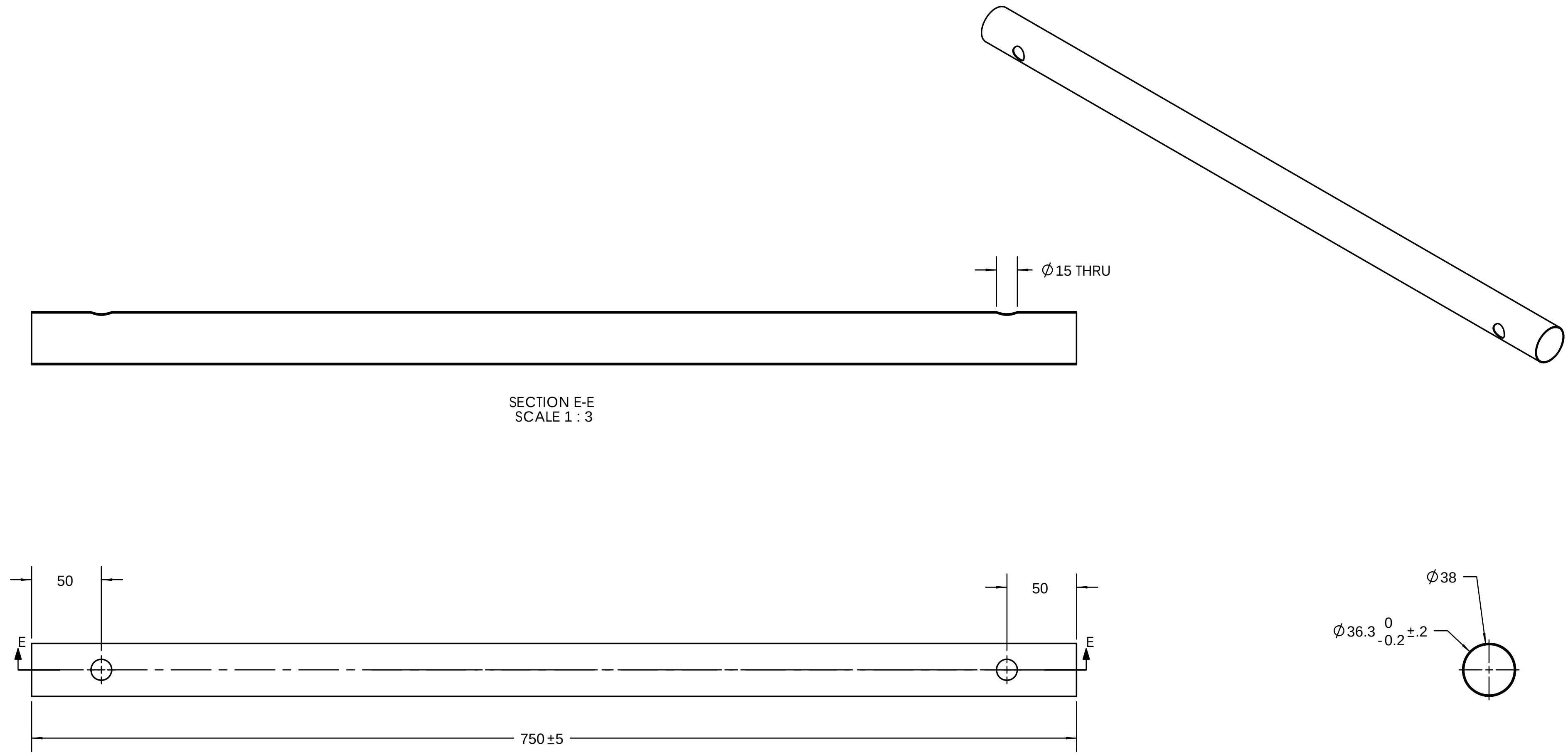


DETAIL D
SCALE 1 : 2

NOTES:

- ALL RINGS HAVE SAME DIMENSIONS.
- ALL RINGS ARE SPACED EVENLY AROUND THE E-W AXIS
- ALL RINGS HAVE A 5MM RADIUS FILLET.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: X ± .5 mm XX ± 1 mm XXX ± 2 mm ANGULAR: ± 2°	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
			TITLE: BALL		
	NAME	SIGNATURE	DATE		
DRAWN	STEVE ROSE		1/17/11	MATERIAL:	DWG NO. BB05	A3
CHK'D					
APPV'D					
				WEIGHT:	SCALE:1:10	SHEET 1 OF 1



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SURFACE FINISH:
TOLERANCES:
LINEAR: X ± .5 mm
XX ± 1 mm
XXX ± 2 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:

WEIGHT:

TITLE:

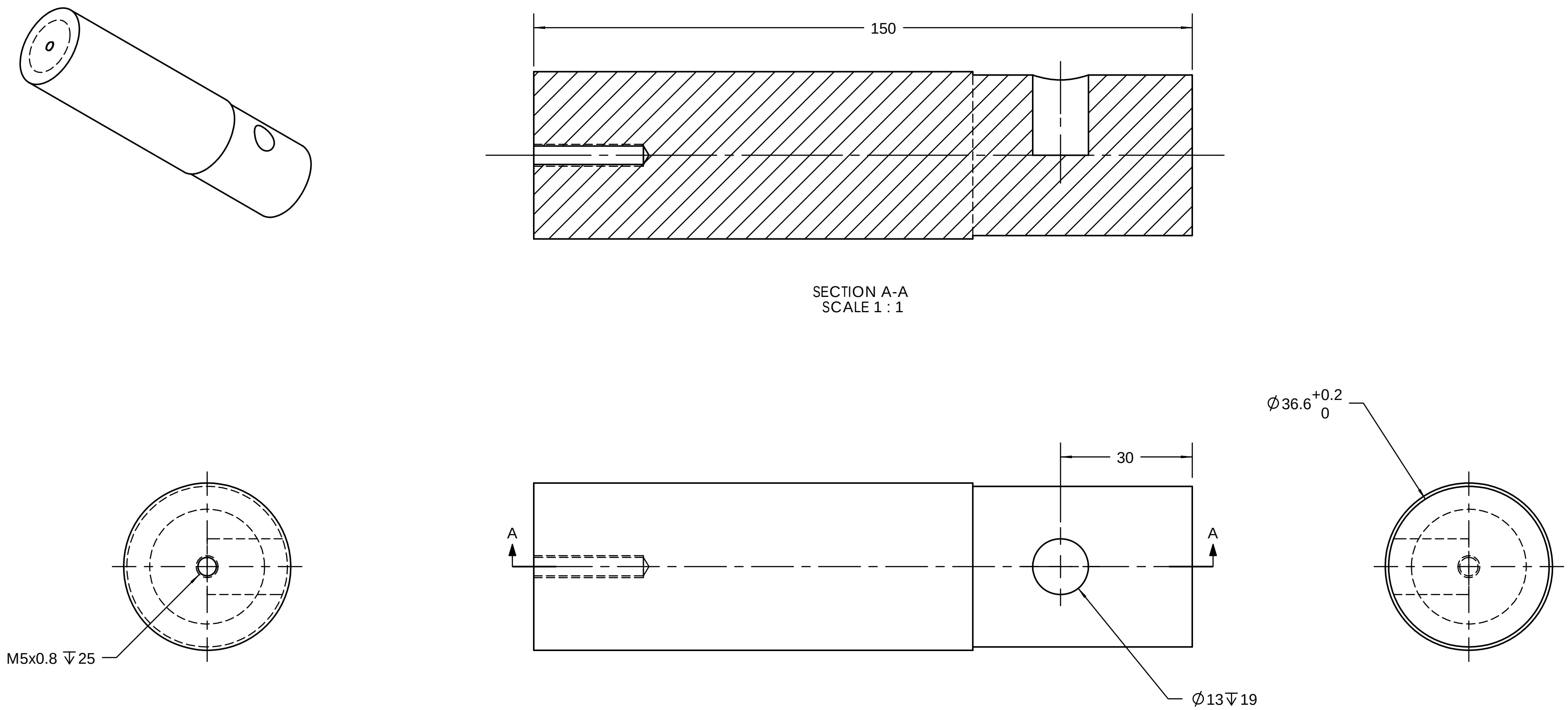
ROD

DWG NO. **BB06**

A3

SCALE:1:5

SHEET 1 OF 1



NOTES:

- 1-1/2"-4 ACME BAR STOCK PURCHASED FROM McMASTER-CARR

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: X ± .5 mm
XX ± 1 mm
XXX ± 2 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

TITLE:

LONG SCREW

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL: GALVINIZED STEEL

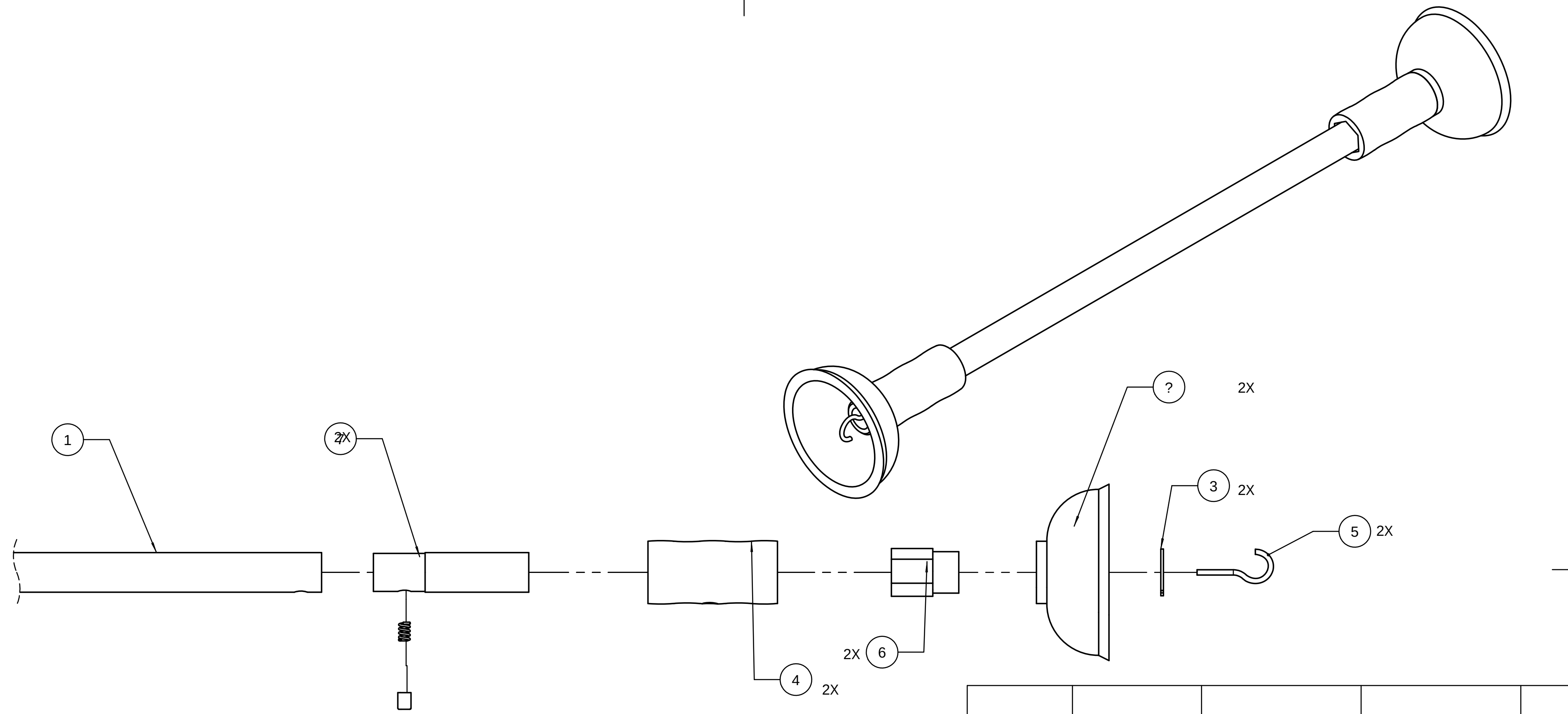
DWG NO. BB10

A3

WEIGHT:

SCALE: 2:1

SHEET 1 OF 1



NOTES:

- PURCHASE PARTS BB07, BB08, BB10 OFF OF McMASTER-CARR
- ASSEMBLY SAME FOR OTHER SIDE OF ROD

ITEM NO.	PART NUMBER	PART DESCRIPTION	MATERIAL	QTY.
1	BB06	LARGE ROD	STEEL 4130	1
2	BB02	PLUNGER	PVC	2
3	BB07	RETAINING RING	GALVINIZED STEEL	2
4	BB01	SLEEVE	PVC	2
5	BB08	HOOK	GALVINIZED STEEL	2
6	BB04	HEX SLEEVE	BRASS	2
7	BB10	LONG SCREW	GALVINIZED STEEL	2
8	Button	BUTTON	PVC	2
9	Spring	SPRING	GALVINIZED STEEL	2

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:

WEIGHT:

DO NOT SCALE DRAWING

REVISION

TITLE:

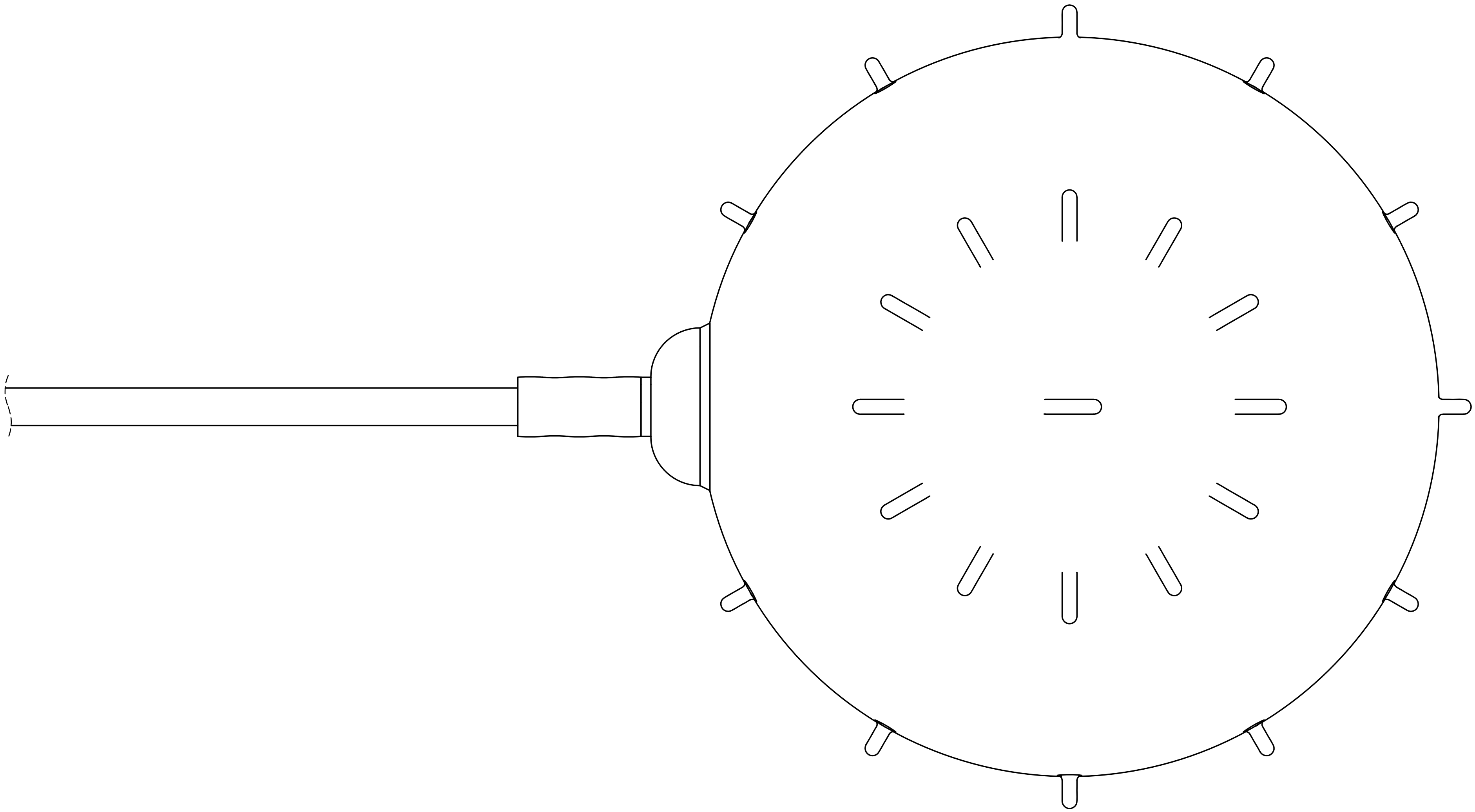
LARGE ROD ASSBLY

DWG NO. BB21

A3

SCALE:1:4

SHEET 1 OF 2



APPLICATION VIEW
SCALE: 1:4

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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: X ± .5 mm
XX ± 1 mm
XXX ± 2 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

TITLE:

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:

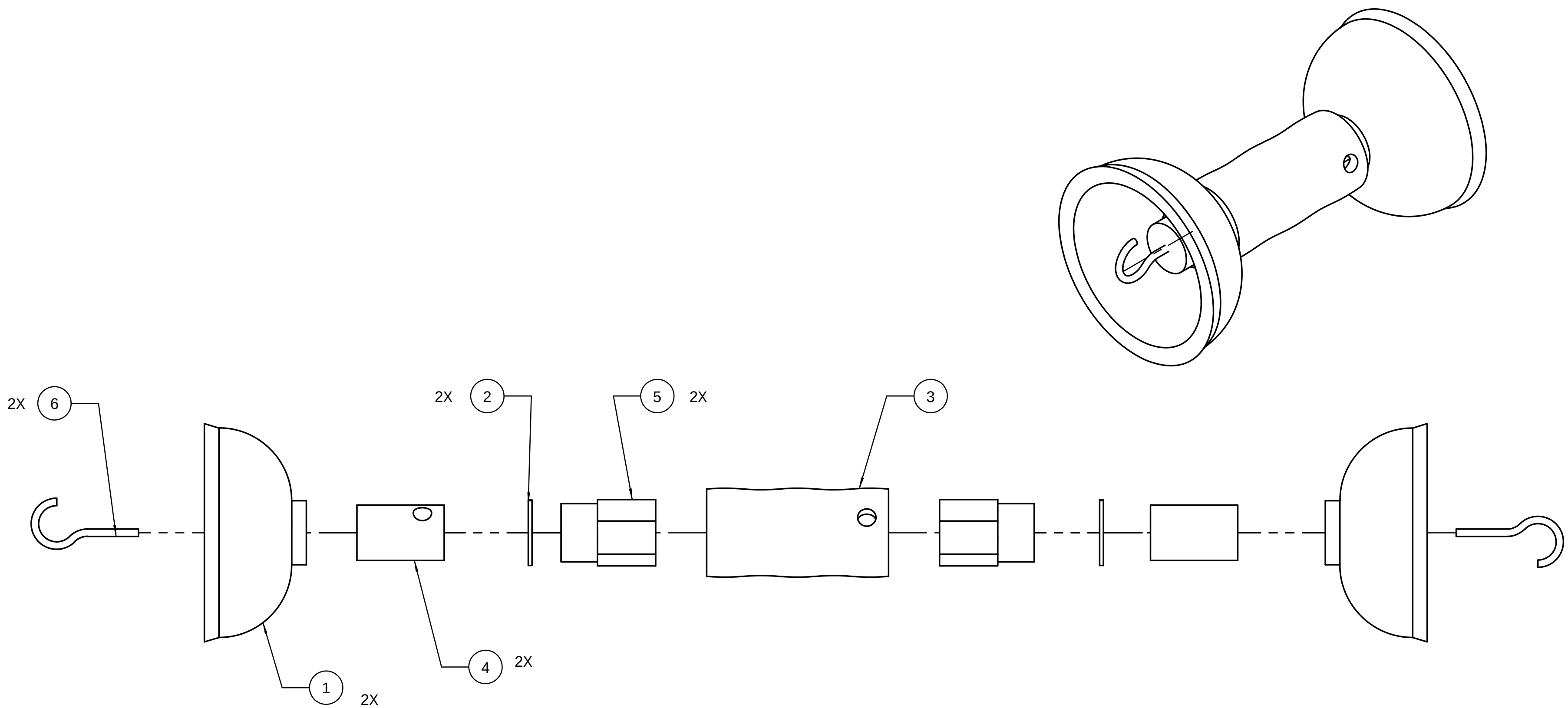
WEIGHT:

DWG NO. BB21

A3

SCALE:1:20

SHEET 2 OF 2



ITEM NO.	PART NUMBER	PART DESCRIPTION	MATERIAL	QTY.
1	BB02	PLUNGER	PVC	2
2	BB07	RETAINING RING	GALVINIZED STEEL	2
3	BB01	SLEEVE	PVC	1
4	BB03	POWER SCREW	GALVINIZED STEEL	2
5	BB04	HEX SLEEVE	BRASS	2
6	BB08	HOOK	GALVINIZED STEEL	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: X ± .5 mm
XX ± 1 mm
XXX ± 2 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

TITLE:

SHORT ROD ASSBLY

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:

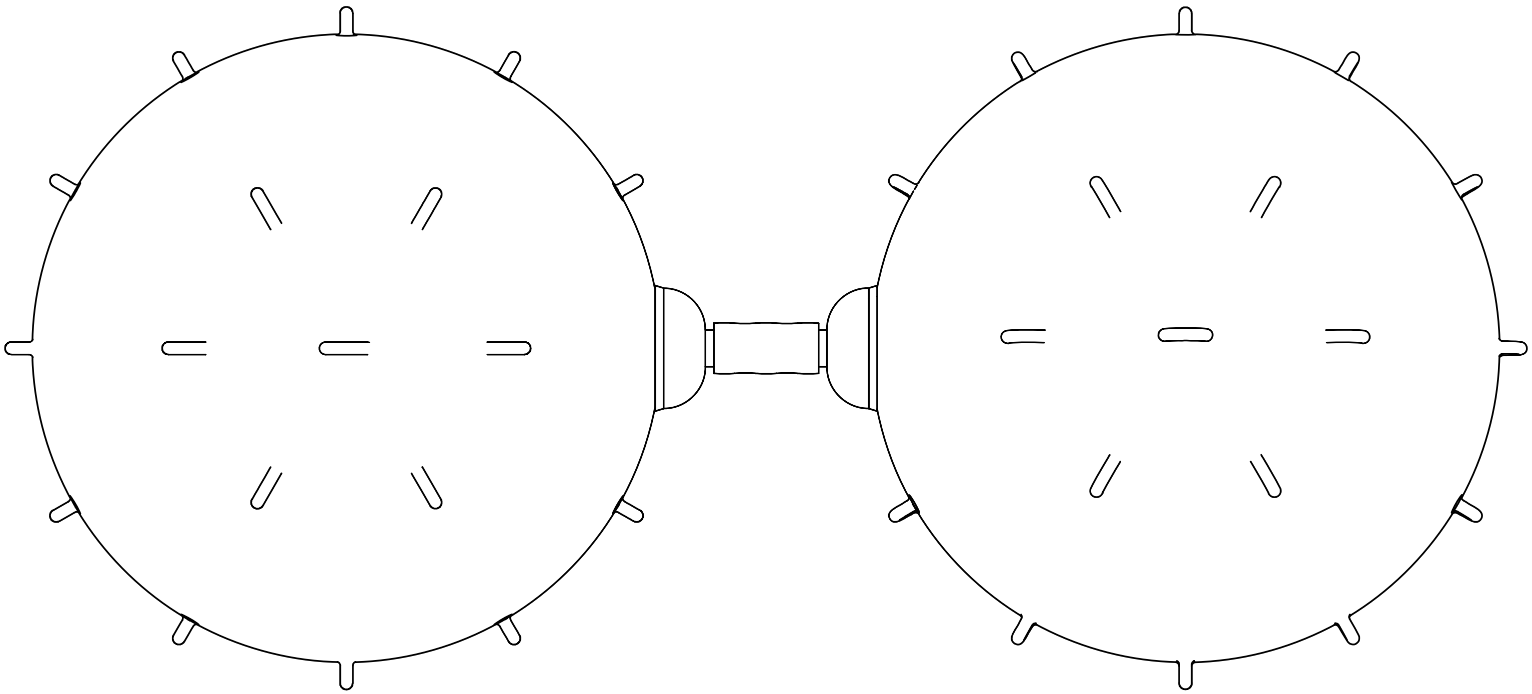
WEIGHT:

DWG NO. BB22

A3

SCALE: 1:3

SHEET 1 OF 2



APPLICATION VIEW
SCALE 1:6

PROPRIETARY AND CONFIDENTIAL

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: X ± .5 mm
XX ± 1 mm
XXX ± 2 mm
ANGULAR: ± 2°

FINISH:

DEBUR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

TITLE:

	NAME	SIGNATURE	DATE
DRAWN	STEVE ROSE		1/17/11
CHK'D			
APPV'D			

MATERIAL:

DWG NO. BB22

A3

WEIGHT:

SCALE:1:24

SHEET 2 OF 2

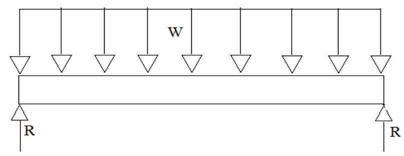
	English (ft, lbs,psf)
	steel
inner radius	0.059583333
J	4.17055E-06
thickness	0.002916667
T	50
L	3.969816273
G	1641600000
theta	0.028992084

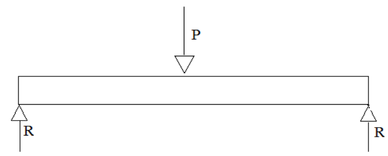
key:	calculated
	assumed

Assuming Max deflection is 1 degree (pi/180 radians)
Material is Al-6061
Torque produced by person is 200 foot pounds

Material is ST-1045

E=30X6
ir=http://www.onlinemetals.com/merchant.cfm?id=283&step=2
t=http://www.onlinemetals.com/merchant.cfm?id=283&step=2

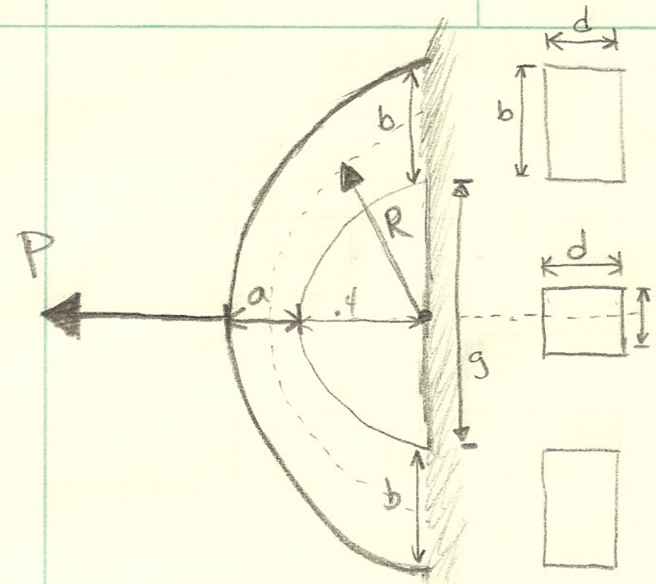




	English (pounds)		English (pounds)	
deflection	-0.04521397	-0.54257	-0.07234	-0.86811
load	125.9504132		500	
I_ring	2.08528E-06			
E	4320000000			
		10.49587		

	MONDO ball	
Variables:	English Units (lb/inches)	Metric (kg/mm)
P	500	
a	0.285	
b	0.7	
d	0.445	
s	0.55	
C	1.2	
E	5.50E+07	
e	7.38E-01	
r_i	4.00E-01	
r_0	8.45E-01	
r_n	5.95E-01	
G	1.20E+06	
A_thin	0.126825	
A_thick	0.3115	
R	1.333	
lamda	0.008375979	
P_max	119389.0265	
key:	testing	
	assumed	
	measured from MONDO BALL	

158-63
502



P = 500 lb.
a = .285 IN.
b = .700 IN.
d = .445 IN.
g = .550 IN.

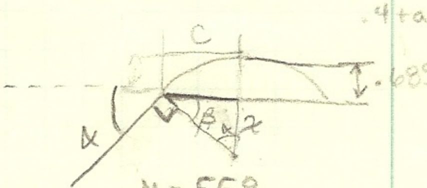
MATERIAL = SHORE A

$$\begin{array}{r} .225 \\ +\ .7 \\ \hline .925 \end{array}$$

$\tan\theta = \frac{.925}{x}$

$x = \frac{.925}{\tan 55}$

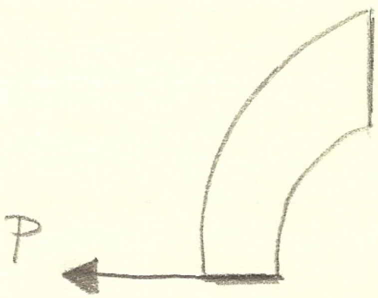
$x = .648''$



$\alpha = 55°$
$\beta = 35°$
$C = .925$

$$\delta = \frac{\pi F R^2}{2AeE} - \frac{\pi F R}{2AE} + \frac{\pi C F R}{2AG}$$

* C = CORRECTION FACTOR (TAB 4.1) = 1.2
* E = MATERIAL VARIABLE
* G = MATERIAL VARIABLE
* $R = x + (.4 + a) = 1.333$ IN.
* $F = P$
* $e = R - r_n = 0$



$\delta = \pi$

ME428/ME481 DVP&R Format

Report Date		1/11/2011	Sponsor	JumpSport					Component/Assembly			REPORTING ENGINEER:	
TEST PLAN										**TEST REPORT**			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibi	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	Hardness	Use durometer for 2 and 4 layers of ball	25-60 Shore A	Gary	DV	5	B	3/1/2011	3/8/2011				
2	Loop Tensile Test	Pull the loop until it breaks in tension	500 lbs	Rosalie	CV	4	A	3/1/2011	3/8/2011				
3	Loop Shear Test	Pull loop in shear until it breaks	500 lbs	Rosalie	CV	4	A	3/1/2011	3/8/2011				
4	Surface Temperature	Measure surface temperature, compare to theoretical higher	<10° F + T_{amb}	Gary	DV	2	B	4/4/2011	4/12/2011				
5	UV Protection	Using Surface Temperature Data to compute reflectivity	Reflectivity > .7	Gary	DV	2	B	4/4/2011	4/12/2011				
6	Quench Test	Heat to 150°F, then quench with 68°F water. Remeasure hardness.	Does not get harder	Gary	DV	2 balls	B	4/4/2011	4/12/2011				
7	Height deflection of ball with rod	Measure vertical displacement of top of ball when statically loaded on bar	1.5 inches from center to new center	Steve	DV	2	B	4/4/2011	4/12/2011				
8	Rotational deflection of ball with rod	Measure rotational displacement of top when statically loaded on bar	15°	Steve	DV	2	B	4/4/2011	4/12/2011				
9	Ball Stand Test	Measure base displacement due to static loading on bar	<1 inch	Steve	DV	2	B	4/4/2011	4/12/2011				
10	Height deflection of ball without rod	Put load on top of ball and measure top deflection	3 inches	Steve	DV	2	B	4/4/2011	4/12/2011				
11	Weight Capacity	Make sure balls can hold specified weight without plastic deformation	2000 lb total, 250 per ball	Steve	DV	1 and 5	B	4/4/2011	4/12/2011				
12	Assembly Time	Put together one formation multiple times for each person. Measure time.	< 15 minutes	Rosalie	PV	3 per person	C	5/16/2011	5/23/2011				
15	Disassembly Time	Disassemble one formation multiple times for each person. Measure time	15 minutes	Rosalie	PV	3 per person	C	5/16/2011	5/23/2011				
16	Space Required	Put together largest configuration	200 sq. ft.	Rosalie	PV	1	C	5/16/2011	5/23/2011				
17	Operating Weight	Weigh balls while inlfated	5 lbs / ball	Rosalie	DV	5	B	5/16/2011	5/23/2011				
18	Packaging Size	Try to fit them in standard sized boxes	6 ft^3± 1 ft^3	Rosalie	PV	1	C	5/16/2011	5/23/2011				
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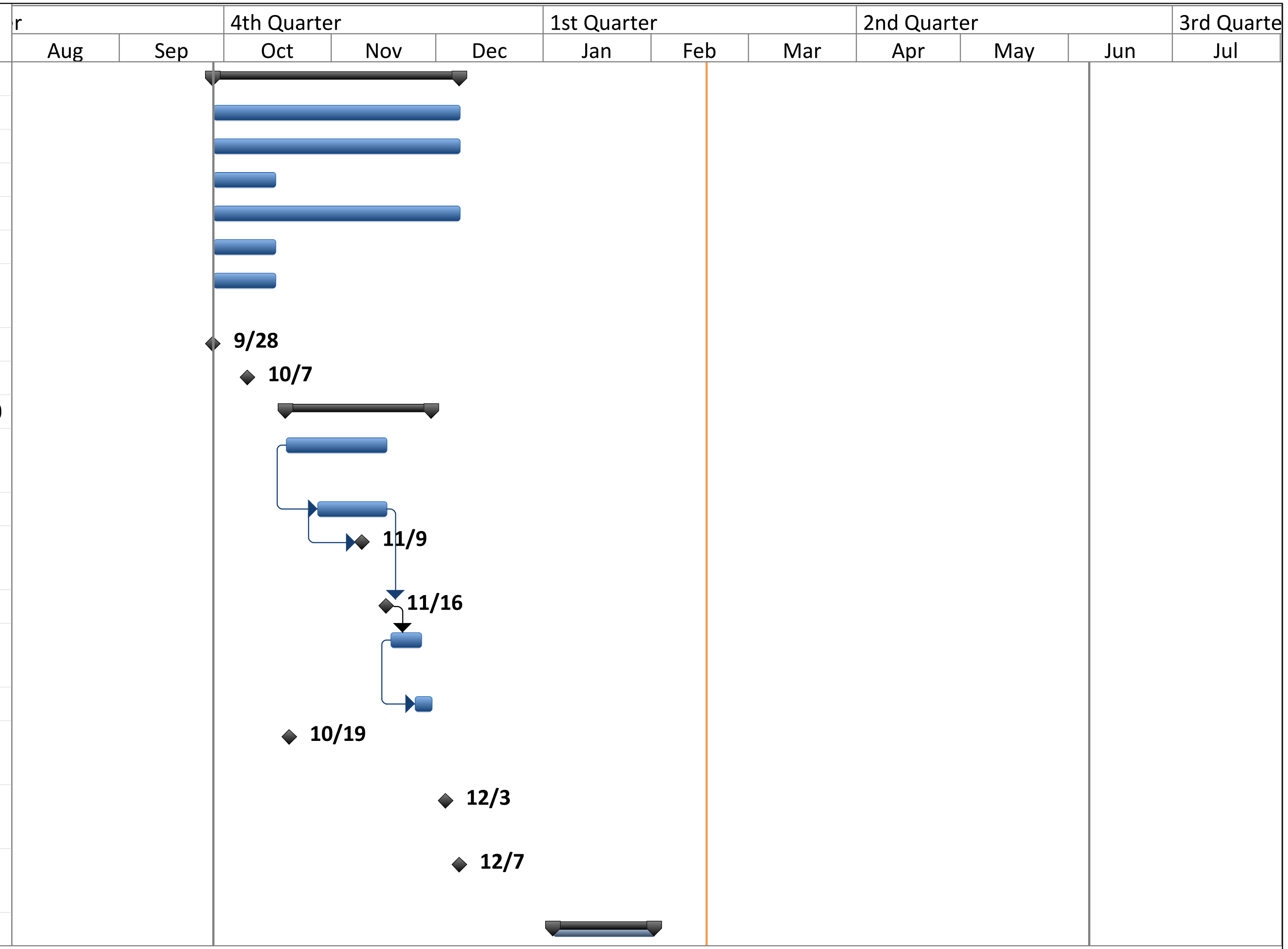
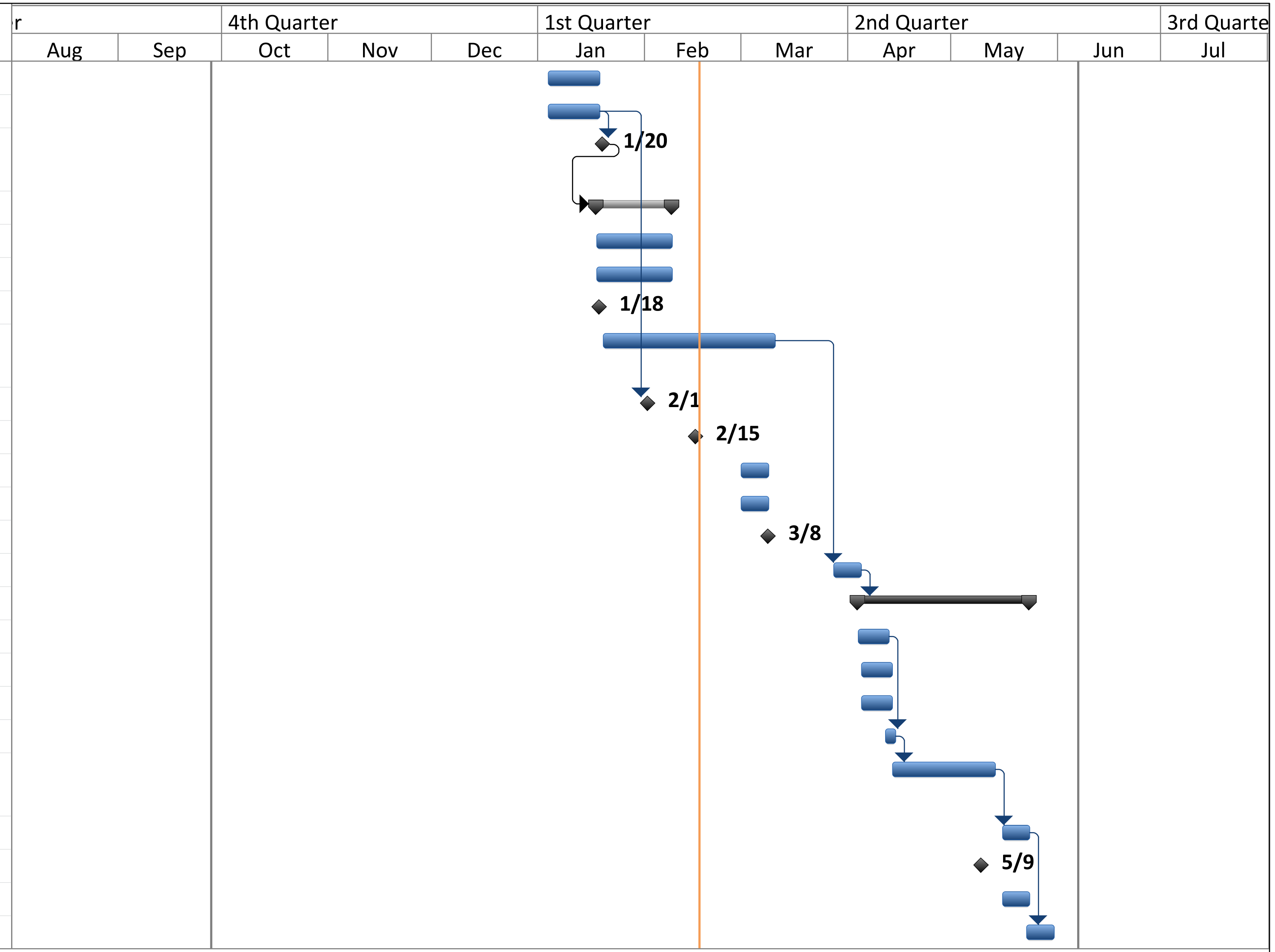
ID		Task Mode	WBS	Task Name	Duration	Start
1			**1**	**Background Research**	**51 days**	**Tue 9/28/10**
2			1.1	Pattent Search	51 days	Tue 9/28/10
3			1.2	Materials Search	51 days	Tue 9/28/10
4			1.3	Company Research	14 days	Tue 9/28/10
5			1.4	Process Research	51 days	Tue 9/28/10
6			1.5	Regulations Search	14 days	Tue 9/28/10
7			1.6	Customer Requirements / Engineering Specs	14 days	Tue 9/28/10
8			2	Email Sponsor	0 days	Tue 9/28/10
9			3	Team Contract	0 days	Thu 10/7/10
10			**4**	**Design**	**30 days**	**Tue 10/19/10**
11			4.1	Conceptualize / Idea Generation	21 days	Tue 10/19/10
12			4.2	Conceptual Models	14 days	Thu 10/28/10
13			4.3	Conceptual Model Presentation	0 days	Tue 11/9/10
14			4.4	Choose Model	0 days	Tue 11/16/10
15			4.5	Make SolidWorks Model	7 days	Thu 11/18/10
16			4.6	Analysis	3 days	Thu 11/25/10
17			5	Project Requirements Document	0 days	Tue 10/19/10
18			6	Conceputal Design Report	0 days	Fri 12/3/10
19			7	Conceputal Design Review with Sponser	0 days	Tue 12/7/10
20			**8**	**Detail Design**	**21 days**	**Tue 1/4/11**



Project: Gantt Chart.mpp
Date: Thu 2/17/11

Task	External Tasks	Manual Task	Finish-only
Split	External Milestone	Duration-only	Deadline
Milestone	Inactive Task	Manual Summary Rollup	Progress
Summary	Inactive Milestone	Manual Summary	
Project Summary	Inactive Summary	Start-only	

ID		Task Mode	WBS	Task Name	Duration	Start
21			8.1	Part Drawings	11 days	Tue 1/4/11
22			8.2	Analysis	11 days	Tue 1/4/11
23			8.3	Decision On Processes	0 days	Thu 1/20/11
24			**9**	**Procurement**	**16 days**	**Tue 1/18/11**
25			9.1	Raw materials	16 days	Tue 1/18/11
26			9.2	Parts	16 days	Tue 1/18/11
27			9.3	Class Presentation	0 days	Tue 1/18/11
28			10	Fabricating (Machine/Mold)	36 days	Thu 1/20/11
29			11	Design Report	0 days	Tue 2/1/11
30			12	Ethics Presentation	0 days	Tue 2/15/11
31			13	Hardness Test	6 days	Tue 3/1/11
32			14	Loop Tests	6 days	Tue 3/1/11
33			15	Project Update Memo	0 days	Tue 3/8/11
34			16	Assembly	6 days	Mon 3/28/11
35			**17**	**Testing**	**36 days**	**Mon 4/4/11**
36			17.1	First Testing	7 days	Mon 4/4/11
37			17.2	Capacity Tests	7 days	Tue 4/5/11
38			17.3	Material Property Tests	7 days	Tue 4/5/11
39			17.4	Punch List	3 days	Tue 4/12/11
40			17.5	Meet Punch List Requirements	22 days	Thu 4/14/11
41			17.6	Second Testing	6 days	Mon 5/16/11
42			17.7	Hardware Demo	0 days	Mon 5/9/11
43			17.8	Functionality Test	6 days	Mon 5/16/11
44			18	Final Assembly	6 days	Mon 5/23/11



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Split	External Milestone	Duration-only	Deadline
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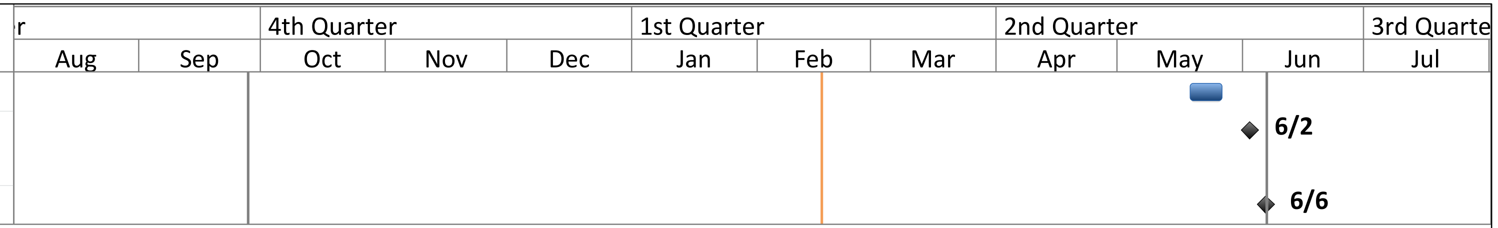
Summary	Inactive Milestone	Manual Summary	
Project Summary	Inactive Summary	Start-only	

ID		Task Mode	WBS	Task Name	Duration	Start
45			19	Expo Presentation Board	6 days	Thu 5/19/11
46			20	Senior Project Design Expo	0 days	Thu 6/2/11
47			21	Final Presentation	0 days	Mon 6/6/11



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